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DESIGN IN NATURE

Elliott & Fry Photo.

Yours sincerely
J. Bell Pettigrew

DESIGN IN NATURE

Illustrated by Spiral and other Arrangements in the Inorganic and Organic Kingdoms as exemplified in Matter, Force, Life, Growth, Rhythms, &c., especially in Crystals, Plants, and Animals. With Examples selected from the Reproductive, Alimentary, Respiratory, Circulatory, Nervous, Muscular, Osseous, Locomotory, and other Systems of Animals

BY

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IN THREE VOLUMES

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ANIMAL LOCOMOTION

§ 328. Extended General Statement and Review of the whole Subject.

The locomotion of animals, as exemplified in walking, swimming, and flying, is a subject of permanent interest to all who seek to trace in the creature proofs of beneficence and design in the Creator. All animals, however insignificant, have a mission to perform—a destiny to fulfil; and their manner of doing it cannot be a matter of indifference, even to a careless observer. The most exquisite form loses much of its grace if bereft of motion, and the most ungainly animal conceals its want of symmetry in the co-adaptation and exercise of its several parts. The rigidity and stillness of death alone are unnatural. So long as things live, move, and have a being, they are agreeable objects in the landscape. They are part and parcel of the great problem of life, and as we are all hastening towards a common goal, it is but natural that we should take an interest in the movements of our fellow-travellers. As the locomotion of animals is intimately associated with their habits and modes of life, a wide field is opened up, teeming with incident, instruction, and amusement. No one can see a bee steering its course with admirable precision from flower to flower in search of nectar; or a swallow darting like a flash of light along the lanes in pursuit of insects; or a wolf panting in breathless haste after a deer; or a dolphin rolling like a mill-wheel after a shoal of flying-fish, without feeling his interest keenly awakened.

Nor is this love of motion confined to the animal kingdom. We admire a cataract more than a canal; the sea is grander in a hurricane than in a calm; and the fleecy clouds which constantly flit overhead are more agreeable to the eye than a horizon of tranquil blue, however deep and beautiful. We never tire of sunshine and shadow when together: we readily tire of either by itself. Inorganic changes and movements are scarcely less interesting than organic ones. The disaffected growl of the thunder, and the ghastly lightning flash, scorching and withering whatever it touches, forcibly remind us that everything above, below, and around is in motion. Of absolute rest, as Mr. Grove, after much patient research, has shown, nature gives us no evidence. All matter, whether living or dead, whether solid, liquid, or gaseous, is constantly changing form: in other words, is constantly moving. It is well it is so; for those incessant changes in inorganic matter and living organisms introduce that fascinating variety which palls not upon the eye, the ear, the touch, the taste, or the smell. If an absolute repose everywhere prevailed, and plants and animals ceased to grow; if day ceased to alternate with night and the fountains were dried up or frozen; if the shadows refused to creep, the air and rocks to reverberate, the clouds to drift, and the great race of created beings to move, the world would be no fitting habitation for man. In change he finds his present solace and future hope. The great panorama of life is interesting because it moves. One change involves another, and everything which co-exists, co-depends. This co-existence and inter-dependence cause us not only to study ourselves, but everything around us. By discovering natural laws we are permitted in God's good providence to harness and yoke natural powers, and already the giant Steam drags along at incredible speed the rumbling car and swiftly gliding boat; the quadruped has been literally outraced on the land, and the fish in the sea; each has been, so to speak, beaten in its own domain. That the tramway of the air may and will be traversed by man's ingenuity at some period or other, is, reasoning from analogy and the nature of things, equally certain. If there were no flying things—if there were no insects, bats, or birds as models, artificial flight (such are the difficulties attending its realisation) might well be regarded as an impossibility. As, however, the flying creatures are legion, both as regards number, size, and pattern, and as the bodies of all are not only manifestly heavier than the air, but are composed of hard and soft parts, similar in all respects to those composing the bodies of the other members of the animal kingdom, we are challenged to imitate the movements of the insect, bat, and bird in the air, as we have already imitated the movements of the quadruped on the land and the fish in the water. We have made two successful steps, and have only to make a third to complete that wonderfully perfect and very comprehensive system of locomotion which we behold in nature. Until this third step be taken, our artificial appliances for transit can only be considered imperfect and partial. Those authors who regard artificial flight as impracticable sagely remark that the land supports the quadruped and the water the fish. This is quite true,

but it is equally true that the air supports the bird, and that the evolutions of the bird on the wing are quite as safe and infinitely more rapid and beautiful than the movements of either the quadruped on the land or the fish in the water. What, in fact, secures the position of the quadruped on the land, the fish in the water, and the bird in the air, is the life ; and by this I mean that prime moving or self-governing power which co-ordinates the movements of the *travelling surfaces* (whether feet, fins, or wings) of all animals, and adapts them to the medium on which they are destined to operate, whether this be the comparatively unyielding earth, the mobile water, or the still more mobile air. Take away this life suddenly—the quadruped falls downwards, the fish (if it be not specially provided with a swimming bladder) sinks, and the bird gravitates of necessity. There is a sudden subsiding and cessation of motion in either case, but the quadruped and the fish have no advantage over the bird in this respect. The savants who oppose this view exclaim not unnaturally that there is no great difficulty in propelling a machine either along the land or the water, seeing that both these media support it. There is, I admit, no great difficulty now, but there were apparently insuperable difficulties before the locomotive and steamboat were invented. *Weight*, moreover, instead of being a barrier to artificial flight, is absolutely necessary to it. This statement is quite opposed to the commonly received opinion, but is nevertheless true. No bird is lighter than the air, and no machine constructed to navigate it should aim at being specifically lighter. What is wanted is a reasonable but not excessive weight, and a duplicate (in principle if not in practice) of those structures and movements which enable insects, bats, and birds to fly. Until the structure and uses of wings are understood, the way of "an eagle in the air" must of necessity remain a mystery. The subject of flight has never, until quite recently, been investigated systematically or rationally, and, as a result, very little is known of the laws which regulate it. If these laws were understood, and we were in possession of trustworthy data for our guidance in devising artificial pinions, the formidable Gordian knot of flight, there is reason to believe, could be readily untied.

That artificial flight is possible is proved beyond doubt—first, by the fact that flight is a natural movement ; and second, because the natural movements of walking and swimming have already been successfully imitated.

The very obvious bearing which natural movements have upon artificial ones, and the relation which exists between organic and inorganic movements, invest the subject of locomotion with a peculiar interest.

It is the blending of natural and artificial progression in theory and practice which gives to the one and the other their chief charm. The history of artificial progression is essentially that of natural progression. The same laws regulate and determine both. The wheel of the locomotive and the screw of the steamship apparently greatly differ from the limb of the quadruped, the fin of the fish, and the wing of the bird ; but, as I shall show in the sequel, the curves which go to form the wheel and the screw are found in the travelling surfaces of all animals, whether they be limbs (furnished with feet), or fins, or wings.

It is a remarkable circumstance that the undulations or waves made by the wing of an insect, bat, or bird, when those animals are fixed or hovering before an object, and when they are flying, correspond in a marked manner with the undulations described by the stationary and progressive waves in fluids, and likewise with the waves of sound. This coincidence would seem to argue an intimate relation between the wing and the medium on which it is destined to operate, whether air or water. Can it be that the animate and inanimate world in this as in other things reciprocate, and that the travelling organs of animals are made to impress the inanimate bodies in precisely the same manner as the inanimate bodies impress each other ? This much seems certain : The wind communicates to the water similar impulses to those communicated to it by the fish in swimming ; and the wing when it is made to vibrate, impinges upon the air as an ordinary sound does. The extremities of bipeds and quadrupeds, moreover, describe waved tracks on the land when walking and running ; so that one great law apparently determines the course of the bird in the air, the fish in the water, and the biped and quadruped on the land.

We are, unfortunately, not taught to regard the travelling surfaces and movements of animals as correlated in any way to surrounding media, and, as a consequence, are apt to consider walking as distinct from swimming, and walking and swimming as distinct from flying, than which there can be no greater mistake. Walking, swimming, and flying are in reality only modifications of each other. Walking merges into swimming, and swimming into flying, by insensible gradations. The modifications which result in walking, swimming, and flying are necessitated by the fact that the earth affords a greater amount of support than the water, and the water than the air.

That walking, swimming, and flying represent integral parts of the same problem is proved by the fact that most quadrupeds swim as well as walk, and some even fly ; while many marine animals walk as well as swim, and insects and birds walk, swim, and fly indiscriminately. When the land animals, properly so called, are in the habit of taking to the water or the air ; or the inhabitants of the water are constantly taking to the land or the air ; or the insects and birds which are more peculiarly organised for flight, spend much of their time on the land and in the water ; their organs of locomotion must possess those peculiarities of structure which characterise, as a class, those animals which live on the land, in the water, or in the air respectively.

In this we have an explanation of the gossamer wing of the insect—the curiously modified hand of the bat and bird—the webbed hands and feet of the beaver, otter, ornithorhynchus, seal, and walrus—the expanded tail of the whale, porpoise, dugong, and manatee—the feet of the ostrich, apteryx, and dodo, exclusively designed for running—the feet of the ducks, gulls, and petrels, specially adapted for swimming—and the wings and feet of the penguins, auks, and guillemots, especially designed for diving. Other and intermediate modifications occur in the flying-fish, flying lizard, and flying squirrel; and some animals, as the frog, newt, and several of the aquatic insects (the ephemera or may-fly for example [1]) which begin their career by swimming, come ultimately to walk, leap, and even fly.[2] These points are illustrated at Plate I. p. 81.

Every degree and variety of motion, which is peculiar to the land- and to the water- and air-navigating animals as such, is imitated by others which take to the elements in question secondarily or at intervals.

Of all animal movements, flight is indisputably the finest. It may be regarded as the poetry of motion. The fact that a creature as heavy, bulk for bulk, as many solid substances, can by the unaided movements of its wings urge itself through the air with a speed little short of a cannon-ball, fills the mind with wonder. Flying (if I may be allowed the expression) is a more unstable form of locomotion than that of walking and swimming; the instability increasing as the medium traversed becomes less dense. It, however, does not essentially differ from the other two, and I shall be able to show in the following pages, that the materials and forces employed in flight are literally the same as those employed in walking and swimming. This is an encouraging circumstance as far as artificial flight is concerned, as the same elements and forces employed in constructing locomotives and steamboats may, and probably will at no distant period, be successfully employed in constructing flying machines. Natural flight is a vito-mechanical problem. It is warped in and out with the other animal movements, and forms a link of a great chain of motion which drags its weary length over the land, through the water, and, notwithstanding its weight, through the air. To understand flight, it is necessary to understand walking and swimming. These naturally precede flying.

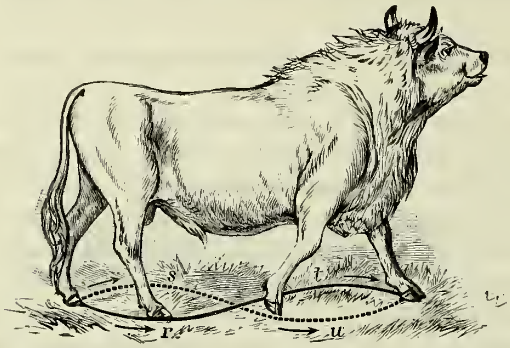
In the animal kingdom the movements are adapted either to the land, the water, or the air; these constituting the three great highways of nature. As a result, the instruments by which locomotion is effected are specially modified. This is necessary because of the different densities and the different degrees of resistance furnished by the land, water, and air respectively. On the land the extremities of animals encounter the *maximum* of *resistance*, and occasion the *minimum* of *displacement*. In the air, the pinions experience the *minimum* of *resistance*, and effect the *maximum* of *displacement;* the water being intermediate both as regards the degree of resistance offered and the amount of displacement produced. The speed of an animal is determined by its shape, mass, and power, and the density of the medium on or in which it moves. It is more difficult to walk on sand or snow than on a macadamised road. In like manner (unless the travelling surfaces are specially modified), it is more troublesome to swim than to walk, and to fly than to swim. This arises from the displacement produced, and the consequent want of support. The land supplies the fulcrum for the levers formed by the extremities or travelling surfaces of animals with terrestrial habits; the water furnishes the fulcrum for the levers formed by the tail and fins of fishes, sea mammals, &c.; and the air the fulcrum for the levers formed by the wings of insects, bats, and birds. The fulcrum supplied by the land is immovable; that supplied by the water and air movable. The immobility and mobility of the fulcrum constitute the principal difference between walking, swimming, and flying; the travelling surfaces of animals increasing in size as the medium to be traversed becomes less dense and the fulcrum more movable. Thus terrestrial animals have smaller travelling surfaces than amphibia, amphibia than fishes, and fishes than insects, bats, and birds (Fig. 299, A, B, C).

Another point to be studied in connection with unyielding and yielding fulcra, is the resistance offered to forward motion. A land animal is supported by the earth, and experiences little resistance from the air through which it moves, unless the speed attained is high. Its principal friction is that occasioned by the contact of its travelling surfaces with the earth. If these are few and small, the speed is generally great, as in quadrupeds. A fish, or sea mammal, is of nearly the same specific gravity as the water it inhabits; in other words, it is supported with as little or less effort than a land animal. As, however, the fluid in which it moves is more dense than air, the resistance it experiences in forward motion is greater than that experienced by land animals, and by insects, bats, and birds. As a consequence fishes are for the most part of a pointed oval shape; this being the form

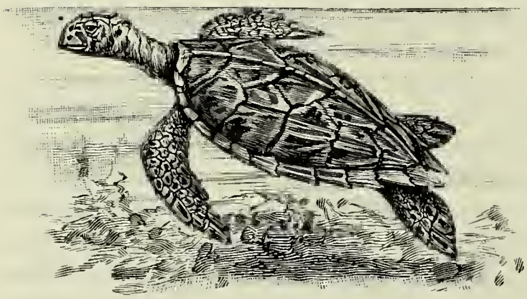
[1] The ephemeræ in the larva and pupa state reside in the water, concealed during the day under stones or in horizontal burrows which they form in the banks. Although resembling the perfect insect in several respects, they differ materially in having longer antennæ, in wanting ocelli, and in possessing horn-like mandibles; the abdomen has, moreover, on each side a row of plates, mostly in pairs, which are a kind of false branchiæ, and which are employed not only in respiration, *but also as paddles.* (Cuvier's "Animal Kingdom," p. 576. London, 1840.)

[2] Kirby and Spence observe that some insects which are not naturally aquatic, do, nevertheless, swim very well if they fall into the water. They instance a kind of grasshopper (*Acridium*), which can paddle itself across a stream with great rapidity by the powerful strokes of its hind legs. ("Introduction to Entomology," 5th edit., 1828, p. 360.) Nor should the remarkable discovery by Sir John Lubbock (Lord Avebury) of a swimming insect (*Polynema natans*), which uses its wings *exclusively as fins*, be overlooked. (*Linn. Trans.*, vol. xxiv. p. 135.)

calculated to cleave the water with the greatest ease. A flying animal is immensely heavier than the air. The support which it receives, and the resistance experienced by it in forward motion, are reduced to a minimum. Flight, because of the rarity of the air, is very much more rapid than either walking, running, or swimming. The flying animal receives support from the air by increasing the size of its travelling surfaces, which act after the manner of twisted inclined planes or kites. When an insect, a bat, or a bird is launched in space, its weight (from the tendency of all bodies to fall vertically downwards) presses upon the inclined planes or kites formed by the wings in such a manner as to become converted directly into a *propelling*, and indirectly into a *buoying* or supporting power. This can be proved by experiment, as I shall show subsequently. But for the share which the weight or mass of the flying animal takes in flight, the protracted journeys of birds of passage would be impossible. Some authorities are of opinion that birds even sleep on the wing. Certain it is that the albatross, that prince of the feathered tribe, can sail about for a whole hour without once flapping its pinions. This can only be done in virtue of the weight of the bird acting upon the inclined planes or kites formed by the wings which are supported by the air in motion. When a bird flies in still air its wings, unless very large, are moved with great velocity. Contrary to all expectation, as I pointed out in 1867,[1] the wings strike downwards and *forwards* during the down stroke, and upwards and *forwards* during the up stroke. In order to support the body of the bird which is in motion and which tends to fall in a downward and *forward* direction, the wings must be carried in front of the body, especially during the down stroke. A grouse when shot on the wing falls downwards and forwards in a curve, and to prevent the downward and forward fall of the body in motion, the living bird always causes its wings to strike *forwards* or in advance of its body. The wings, as I explained in 1867, not only strike downwards and forwards during the down stroke and upwards and forwards during the up stroke, but they also pull the body forward—a view fully corroborated of late years by instantaneous photographs of flying birds. The old idea was that the wings pushed the body forward: the result is the same, but the *modus operandi* is wholly different. No one ever saw a bird deliver the down stroke of the wings either vertically downwards, or downwards and backwards. The explanation here given, paradoxical as it may appear, is readily understood when the problem of flight is explained on strictly mechanical principles. The wings, as I also demonstrated in 1867, act as true kites, both during the down and up strokes.



A



B

C

FIG. 299.—A. Chillingham bull (*Bos scoticus*). Illustrates the small travelling extremities adapted for the land. *r, s, t, u*, figure-of-8 movements made by the feet in walking (the Author, 1867).
B. The turtle (*Chelonia imbricata*). Enlarged travelling extremities (flippers) adapted for the water (the Author, 1867).
C. The bat (*Phyllorhina gracilis*). Greatly expanded travelling extremities adapted for the air (the Author, 1867).

The following abstract from my paper, "On the various Modes of Flight in Relation to Aeronautics," explains the point: "All wings obtain their leverage by presenting oblique surfaces to the air, the degree of obliquity gradually increasing in a direction from behind forwards and downwards during extension when the sudden or effective stroke is being given, and gradually decreasing in an opposite direction during flexion or when the wing is being slowly recovered preparatory to making a second stroke. The effective stroke in insects, and this holds true also of birds, is therefore delivered *downwards* and *forwards*, and not, as the majority of writers believe, vertically, or even slightly backwards. This arises from the curious circumstance that insects and birds when flying actually fall through the medium which elevates them; their course being indicated by the resultant of two forces, namely, that of gravity, pulling vertically downwards, and that of the wing acting at a given angle in an upward direction. The wing of the bird acts after the manner of a boy's kite, the only difference being that the kite is *pulled forwards* upon the wind by the string and the hand, whereas

[1] "The various Modes of Flight in Relation to Aeronautics." (*Proceedings of the Royal Institution of Great Britain*, March 22, 1867.)

in the bird, the wing is *pushed forwards* on the wind by the weight of the body and the life residing in the pinion itself" (Figs. 300 and 301).

The statement made by me in 1867 to the effect that the wing strikes downwards and *forwards* and upwards and *forwards* in flight was the occasion of a keen controversy on the part of the mathematicians at Cambridge and elsewhere. They, without having sufficiently examined the proofs published by me, or having repeated my original experiments, maintained on purely theoretical grounds, that it was physically impossible for the wing to act as I said it did. They, however, did not realise that the body of a volant animal is inclined obliquely upwards in flight, that the wing is a highly elastic structure which yields at its tip and along its posterior margin when made to vibrate, that the air upon which the wing operates furnishes an exceedingly mobile fulcrum, that the wing is carried forward with the body in free flight—its under surface acting as a kite during both the down and up strokes, and that in order to support the flying creature which tends to fall downwards and *forwards* the wings must of necessity be, for the most part, in advance of the mass they are bearing upwards and onwards.

Having abundantly satisfied myself of the accuracy of my observations by a careful and prolonged study of the flight of insects, birds, and bats, and having performed a very large number of experiments with natural and

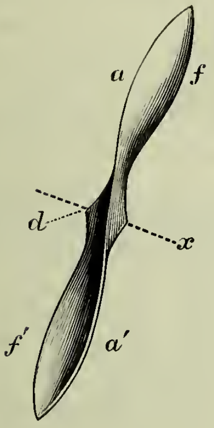


Fig. 300.

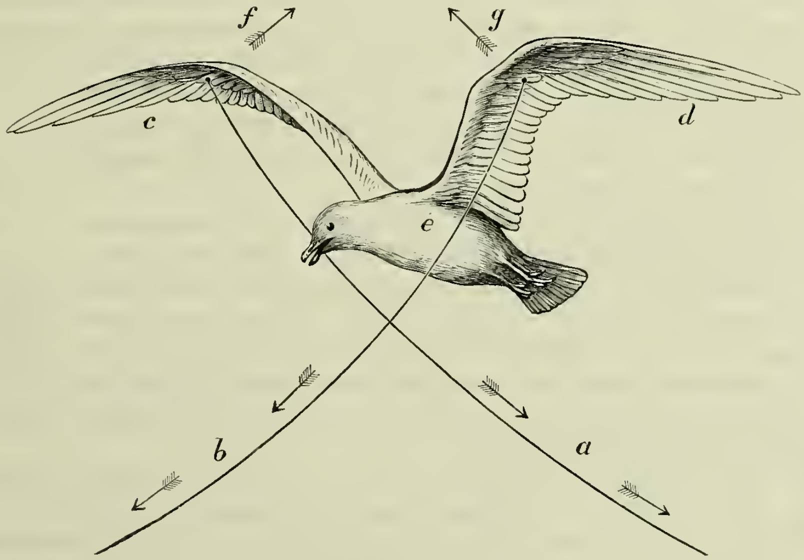


Fig. 301.

Fig. 300.—Shows the downward and forward stroke made by the wing of the bird in flight. *x*, Axis of the body of the bird, *d*, root of the wing; *f*, *f′*, thick margin of the wing; *a*, *a′*, spiral track described by the thin margin and tip of the wing (the Author, 1867).

Fig. 301.—Shows the kite action of the wing in the gull. *a*, *b*, Kite strings for each wing which tend to pull the wings (*c*, *d*) downwards and forwards. The body and weight of the bird (*e*) perform a similar rôle. The kites formed by the wings tend to rise in the direction *f*, *g*; the line of flight is consequently between *a*, *b* and *f*, *g* (the Author, 1867).

artificial wings, all of which were published, I did not seriously attempt to convince or convert the closet philosophers who, as usual, were as dogmatic as they were bigoted. Instantaneous photography came ultimately to my aid and gave me an easy victory over my opponents. Snap-shots taken of flying birds conclusively proved that the wing which, at the beginning of the down stroke, occupies a position corresponding with the root of the tail of the bird, is, at the termination of the down stroke, more than half the length of the body in advance of the beak of the bird. The accuracy of instantaneous photographs cannot be doubted or even questioned. I give specimens of instantaneous photographs of flying birds in corroboration of the above in future sections of the work.

The weight of the body plays an important part in walking and swimming, as well as in flying. A biped which advances by steps and not by leaps may be said to roll diagonally over its extremities,[1] the foot of the extremity which happens to be upon the ground for the time forming the centre of a circle, a segment of which is described by the trunk in forward motion. In like manner the foot which is off the ground and swinging forward pendulum-fashion in space, may be said to roll or rotate upon the trunk; the head of the femur forming the centre of a circle, a portion of the circumference of which is described by the advancing foot. A double rolling movement is thus established; the body rolling on the extremity the one instant, the extremity rolling on the trunk the next. During these movements the body rises and falls. The double rolling movement is necessary

[1] This is also true of quadrupeds. It is the posterior part of the feet which is set down first.

not only to the progression of bipeds, but also to that of quadrupeds. As the body cannot advance without the extremities, so the extremities cannot advance without the body. The double rolling movement is necessary to continuity of motion. If there was only one movement, there would be dead points or halts in walking and running, similar to what occur in leaping. The continuity of movement necessary to progression in some bipeds (man for instance) is further secured by a pendulum-movement in the arms as well as in the legs, the right arm swinging before the body when the left arm swings behind it, and the converse. The right leg and left arm advance simultaneously to form one step, and alternate with the left leg and right arm, which likewise advance together to form a second step. This gives rise to a double twisting of the body at the shoulders and loins. The legs and arms when advancing move in curves; the convexities of the curves made by the right leg and left arm, which advance together when a step is being made, being directed outwards (that is, away from the mesial line of the body), and forming, when placed together, a more or less symmetrical ellipse. If the curves made by the right arm and left leg, and the left arm and right leg respectively, be united, they form waved lines which intersect at every step, as I fully explained in 1867.[1] This arises from the fact that the curves formed by the right and left legs are found alternately on either side of a given line, the same holding true of the right and left arms. Walking is consequently produced by a twisting diagonal movement in the shoulders, loins, and extremities. Without this movement, the momentum acquired by the different portions of the moving mass could not be utilised (Fig. 302).

Fig. 302.—Shows the figure-of-8 curves made by the arms and legs in walking. The solid lines represent the curves made by the legs; the dotted lines those made by the arms (the Author, 1867).

As the momentum acquired by animals in walking, swimming, and flying forms an important factor in those movements, it is necessary that we should have a just conception of the value to be attached to weight when in motion. In the horse, when walking, the stride is something like five feet, in trotting ten feet, but in galloping eighteen or more feet. The stride is in fact determined by the speed acquired by the mass of the body of the horse; the momentum at which the mass is moving carrying the limbs forward.[2]

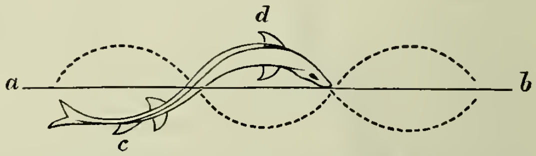


Fig. 303.—Shows the figure-of-8 curves made by the sturgeon in swimming. *a*, *b*, Axis of motion; *c*, caudal curve made by the tail and posterior half of the body; *d*, cephalic curve made by the head and upper half of the body (the Author, 1867).

In the swimming of the fish, the body is thrown into double or figure-of-8 curves, as in the walking of the biped. The twisting of the body, and the continuity of movement which that twisting begets, reappear. The curves formed in the swimming of the fish are never less than two, a *caudal* and a *cephalic* one. They may and do exceed this number in the long-bodied fishes (Fig. 303). The tail of the fish is made to vibrate pendulum-fashion on either side of the spine, when it is lashed to and fro in the act of swimming. It is made to rotate upon one or more of the vertebræ of the spine, the vertebra or vertebræ forming the centre of a lemniscate, which is described by the caudal fin. There is, therefore, an obvious analogy between the tail of the fish and the extremity of the biped. This is proved by the conformation and swimming of the seal—an animal in which the posterior extremities are modified to resemble the tail of the fish. In the swimming of the seal the hind legs are applied to the water by a sculling figure-of-8 motion, in the same manner as the tail of the fish. Similar remarks may be made with regard to the swimming of the whale, dugong, manatee, and porpoise; sea mammals, which still more closely resemble the fish in shape. The double curve into which the fish throws its body in swimming, and which gives continuity of motion, also supplies the requisite degree of steadiness. When the tail is lashed from side to side there is a tendency to produce a corresponding movement in the head, which is at once corrected by the complementary curve. Nor is this all; the cephalic curve, in conjunction with the water contained within it, forms the *point d'appui* for the caudal curve, and *vice versâ*. When a fish swims, the anterior and posterior portions of its body (supposing it to be a short-bodied fish) form curves, the convexities of which are directed on opposite sides of a given line, as is the case in the extremities of the biped when walking. The mass of the

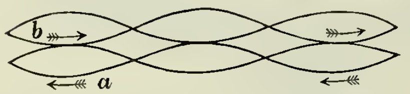


Fig. 304.—Shows the double, spiral, complementary curves made by the feet of the bird in swimming. *a*, Outer curve made by the right foot striking backwards; *b*, inner curve formed by the left foot moving in an opposite direction and recovering itself. In this case the right foot delivers the effective stroke, the left foot the non-effective one. When the effective stroke is delivered the foot is fully expanded, when the non-effective one is given it is folded up and closed. The effective stroke is also delivered more vigorously (the Author, 1867).

[1] Op. cit., March 22, 1867.

[2] "According to Sainbell, the celebrated horse Eclipse, when galloping at liberty, and with its greatest speed, passed over the space of twenty-five feet at each stride, which he repeated two and a third times in a second, being nearly four miles in six minutes and two seconds. The race-horse Flying Childers was computed to have passed over eighty-two feet and a half in a second, or nearly a mile in a minute." (Gamgee.)

fish, like the mass of the biped, when once set in motion, contributes to progression by augmenting the rate of speed. The velocity acquired by certain fishes is very great. A shark can gambol around the bows of a ship in full sail; and a sword-fish (such is the momentum acquired by it) has been known to thrust its tusk through the copper sheathing of a vessel, a layer of felt, four inches of deal, and fourteen inches of oaken plank.[1]

The feet of the bird in swimming describe similar curves to those described by the fish in swimming, and by the extremities of bipeds and quadrupeds in walking and running (Fig. 304).

The wing of the bird does not materially differ from the extremity of the biped or the tail of the fish. It is constructed on a similar plan, and acts on the same principle. The tail of the fish, the wing of the bird, and the extremity of the biped and quadruped, are screws structurally and functionally. In proof of this, compare the bones of the wing of a bird with the bones of the arm of a man, or those of the fore-leg of an elephant, or any other quadruped. In either case the bones are twisted upon themselves like the screw of an auger (Fig. 305).

The wing of the bird during extension and flexion describes beautiful figure-of-8 complemental curves; the curves made in extension being the converse of those made in flexion (Figs. 306 and 307).

The wing of the bird reverses its curves during extension and flexion (Figs. 308, 309, and 310).

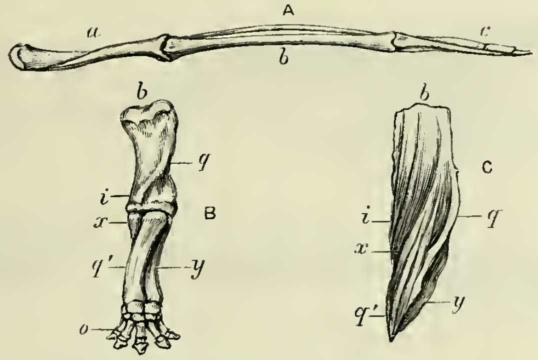


FIG. 305.—A. Shows the screw formed by the bones of the wing of the bird. *a*, Humerus twisted upon itself; *b*, radius and ulna ditto; *c*, wrist and hand ditto (the Author, 1867).

B. Screw formed by the bones of the foreleg of the elephant; *b*, humerus; *q*, spiral ridge on humerus; *i*, spiral depression ditto; *q'*, spiral ridge formed by radius; *x*, *y*, spiral depression formed by ulna; *o*, bones of foot (the Author, 1867).

C. Wax cast of the interior of the left ventricle of the heart of a deer. Shows beautiful conical-shaped screw. *b*, Base of screw; *q*, *q'* spiral ridge of screw; *i*, *x*, spiral depression on upper side of spiral ridge; *y*, ditto on lower side. The same letters are affixed to figures B and C for comparison (the Author, 1858).

The wing is a screw structurally as well as functionally. Thus the wing when extended and seen from behind in certain positions displays a distinctly spiral contour; the posterior margin twining round the anterior one. The

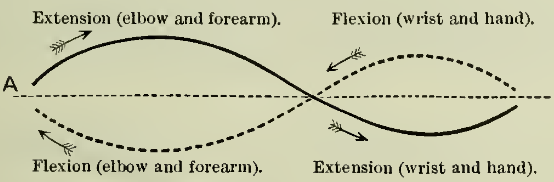


FIG. 306.

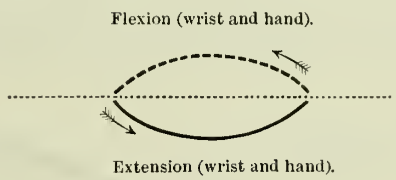


FIG. 307.

FIG. 306.—Shows the opposite spiral curves made by the wing of the bird in extension and flexion when the wing is denuded of feathers. A. Axis of wing movements (the Author, 1867).

FIG. 307.—Ellipse formed by the wrist and carpal and metacarpal bones of the wing of the bird in extension and flexion (the Author, 1867.)

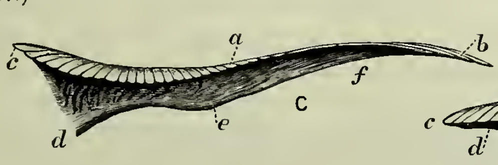


FIG. 308.

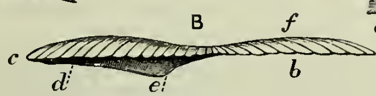


FIG. 309.

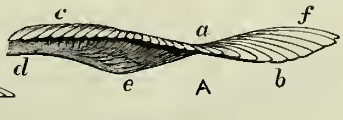


FIG. 310.

FIG. 308.—The wing of the bird as extended. Shows double spiral curve (*c*, *a*, *b*) made by the feathers (primary, secondary, and tertiary) of the posterior margin of the wing. The anterior margin of the wing is seen at *d*, *e*, *f* (the Author, 1867).

FIG. 309.—The same wing midway between extension and flexion. *c*, *b*, Posterior margin of wing; *d*, *e*, *f*, anterior margin, ditto (the Author, 1867).

FIG. 310.—The same wing flexed. *c*, *a*, *b*, Double spiral curve made by the posterior margin of the wing; *d*, *e*, *f*, ditto of the anterior margin. Note.—The curves made by the posterior margin of the wing during flexion are the reverse of those made by it in extension, and form, when placed together, double or figure-of-8 spirals (the Author, 1867).

curves obtained from the two margins are complemental figure-of-8 curves (Fig. 311, 312, and 313). The same is to be said of the margins of the primary feathers at, and near, the tip of the wing (Figs. 314 and 315).

The margins of the wing of the insect, when the wing is made to vibrate, reverse during extension and flexion

[1] A portion of the timbers, &c., of one of Her Majesty's ships, having the tusk of a sword-fish imbedded in it, is to be seen in the Hunterian Museum of the Royal College of Surgeons of England (London).

and form figure-of-8 trajectories in space. The tip of the wing situated between the margins also describes a figure-of-8 track (Figs. 316 and 317).

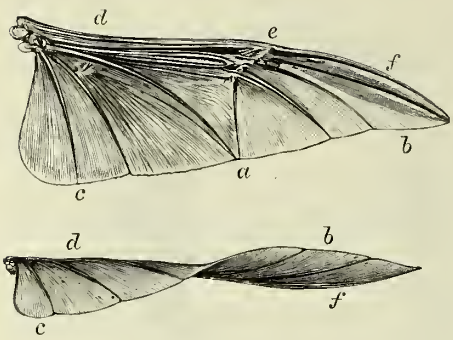


Fig. 311.

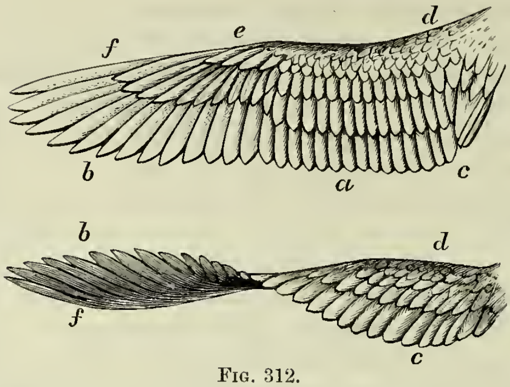


Fig. 312.

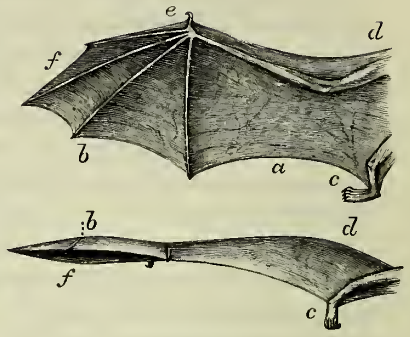


Fig. 313.

Fig. 311.—Wing of a large beetle (*Goliathus micans*). The upper figure shows dorsal surface of wing seen from above; the lower figure shows same wing seen from beneath and behind. *d, e, f,* Anterior margin of wing; *c, a, b,* posterior margin ditto. The letters are the same as in both figures (the Author, 1867).

Fig. 312.—The same views of the wings of the Kestrel or Windhover. The lettering is the same as in Fig. 311 (the Author, 1867).

Fig. 313.—The same views of the wing of a bat (*Phyllocina gracilis*). The lettering is the same as in Figs. 311 and 312 (the Author, 1867).

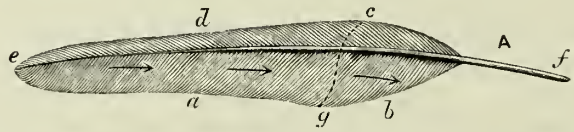


Fig. 314.

Fig. 315.

Figs. 314 and 315.—Show respectively a primary feather seen from above, and from beneath and before. The lettering is the same in both figures. *a, b,* Inner margin of feather; *c, d,* outer margin of feather; *e, f,* midrib of feather. The midrib is curved from above downwards and the margins of the feather display spiral, complemental figure-of-8 curves (right-hand figure). A transverse section of the feather also reveals a spiral, reversing curve seen at *c, g* of Fig. 314 (the Author, 1870).

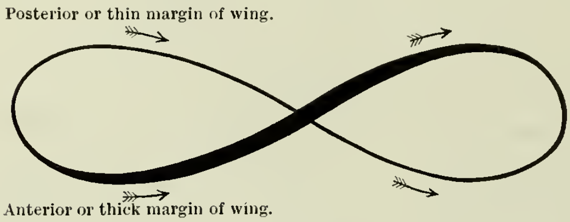


Fig. 316.

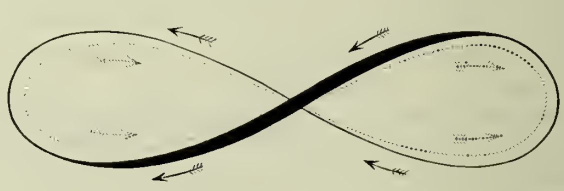


Fig. 317.

Fig. 316.—Figure-of-8 trajectory made by the margins and tip of the wing of the insect in *extension.* The arrows indicate the direction of travel. These movements are reversed during *flexion;* the wing *crossing its own track* during extension and flexion (the Author, 1867).

Fig. 317.—Completed figure. In this figure the dotted line and the dotted arrows indicate the figure-of-8 made by the margins and tip of the wing during *flexion.* The arrows in the completed figure point in opposite directions and shows the reversing, reciprocating movements made by the wing during its vibration (the Author, 1867).

The figure-of-8 action of the wing, as I wrote in 1867,[1] explains how an insect or bird can poise itself in the air; the backward-and-forward reciprocating action of the pinion affording support, but no propulsion. In these instances the backward and forward strokes are made to counterbalance each other. Although the figure-of-8 represents with considerable fidelity the twisting of the wing upon its axis during extension and flexion, when the insect is playing its wings before an object, or still better when it is artificially fixed, it is otherwise when the down stroke is added and the insect is fairly on the wing and progressing rapidly. In this case the wing, in virtue of its being carried forward by the body in motion, describes an undulating or spiral course (Fig. 318).

The figure-of-8 and waved movements made by the wing in captive and free flight are due to the configuration of the wing, its elastic properties, its inherent movements, and the resistance experienced by it in its passage through the air. The wing, as stated, is a screw structurally and functionally. It is applied to the air very much

[1] Op. cit., vol. xxvi., pp. 225, 232, 233, and 234.

as a gimlet or auger is applied to wood when these tools are screwed home and unscrewed. There is a downward and forward movement when the wing is extended and firmly screwed into the air (extension and the down stroke), and a retractile upward movement when the wing is folded and more or less unscrewed (flexion and the up stroke). In these movements, the curves made by the margins of the wings, as explained, are reversed; the posterior margin and tip of the wing yielding slightly according to the degree of pressure applied.

The following is the account given by me of the structure and movements of the wing in 1867 (*Trans. Linn. Soc.*, vol. xxvi., pp. 225, 233, and 266): "All wings are twisted upon themselves structurally. They, moreover, twist upon themselves during their action; so that the course described by them, or, what is the same thing, the blur or impression produced on the eye by their action, is essentially spiral in its nature. . . . The wing of the bird, in virtue of its shape and conformation, acts as a twisted inclined plane; in other words, as a helix or screw—the mere extension of the wing, because of the spiral arrangements of the joints, causing it to rotate from its plane of least resistance till it makes an angle approximating to 30 degrees with the horizon; the reverse of this occurring during flexion. In this respect it intimately agrees with the wing of both the insect and bat, thus proving that however the instruments of flight may be modified, the principle involved is the same in all. . . . The wing in the insect is more flattened than in the bird; and advantage is taken on some occasions of this circumstance to reverse the pinion completely during the down and up strokes—the wing, during its descent, having its interior or thick margin inclined *upwards* and *backwards*, whereas, during its ascent, the anterior or thick margin is inclined *downwards* and *forwards*. . . . The posterior margin of the wing is made to rotate, during the down stroke, in a direction *from above downwards* and *from behind forwards*—the anterior margin travelling in an opposite

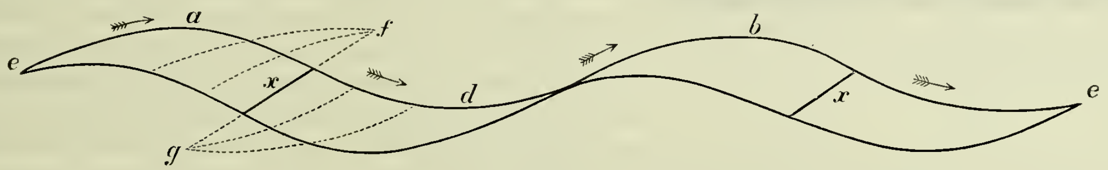


FIG. 318.

FIG. 318.—Waved track (*e, e*) described, by the wing of the insect, bird, and bat in free flight. The thicker parts of the spiral (*a, b*) correspond with the down strokes, the thinner (*e, d, e*) corresponding with the up stroke. At (*f*), the wing is causing its posterior margin to roll downwards until it makes an angle of thirty degrees or so (*x*) with the horizon, a reverse process taking place at *g*, to reduce the resistance made by the wing during the up stroke. The down and up strokes run into each other and are compound movements (the Author, 1867).

direction and reciprocating. The wing may thus be said to attack the air by a screwing movement *from above*. During the up or return stroke, on the other hand, the posterior margin rotates in a direction *from below upwards* and *from before backwards;* so that by a similar but reverse screwing motion, the pinion attacks the air *from beneath*." . . . "*A figure-of-8 compressed laterally and placed obliquely with its long axis running from left to right of the spectator, represents the movements in question. The down and up strokes*, as will be seen from this account, *cross each other;* the wing smiting the air during its descent *from above*, as in the bird and bat, and during its ascent *from below*, as in the flying-fish, and boy's kite."

I especially direct the attention of the reader to the wave and figure-of-8 screwing movements made by the wing, and to the fact that *the down and up strokes of the wing cross each other*, as Professor E. J. Marey, of the College of France, Paris, has quite misrepresented my views on these important points. He has, for example, stated in his work "Animal Mechanism," published in the International Science Series in 1874, p. 260, that "the trajectory of the wing is represented by Dr. Pettigrew by means of Fig. 86." [Professor Marey here copies and reverses my original figure-of-8.] "Four arrows indicate, according to this writer, the direction of movement in the different portions of this trajectory. *These arrows are in the same direction*, and this first fact is opposed to the experiment described in p. 195 (of our work 'Animal Mechanism'), where we have investigated the direction of the movement of the wing, *and have found it pass in opposite directions in the two branches of the* 8. In order to explain the form which he assigns to this trajectory, Dr. Pettigrew admits that in its passage from right to left, the wing describes by its thicker edge the thick branch of the 8, and the thin branch by its narrow edge. *The crossing of the* 8 *therefore would be formed by a complete reversal of the plane of the wing during one of the phases of its revolution*." (The italics in this quotation are mine.) It would be impossible to give a more inaccurate or a more unfair interpretation of my original figure-of-8 than is here attempted. Professor Marey takes what is in reality only one half of my figure-of-8, namely, that made by the wing during *extension*, and makes it represent the whole. In extension the arrows (and properly) all point in one direction, but he omits to state, as I did very clearly in my 1867 memoir on Flight (*vide* abstracts and figures given above), that in flexion everything is reversed, and that the

figure-of-8 made by the wing in *flexion* is the opposite of that made by it in extension, and that as a consequence, the arrows in my completed figure are reversed (*vide* Fig. 317, p. 1080), as in Professor Marey's own figure. I, moreover, distinctly pointed out *that the down and up strokes cross each other.*

That I was quite aware that the arrows in the figure-of-8 made during the extension and flexion of the wing are reversed is abundantly proved by the descriptions and illustrations given in my memoir on Flight in the *Transactions of the Linnean Society* (1867), where the reader will find (pp. 248 and 249) no fewer than nine figures in illustration of this very point. Two of the figures are given at p. 1079 (Figs. 306 and 307).

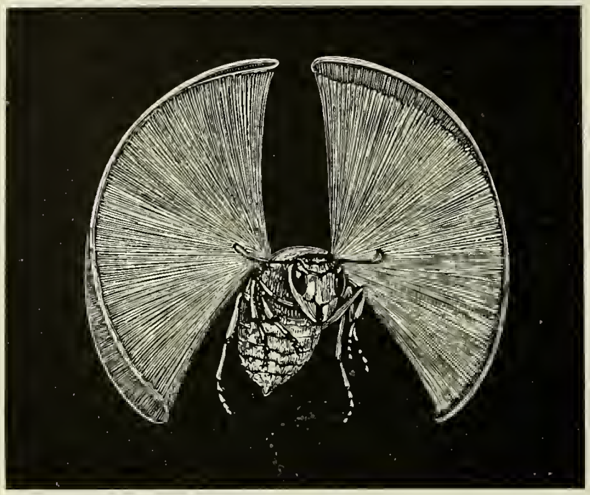
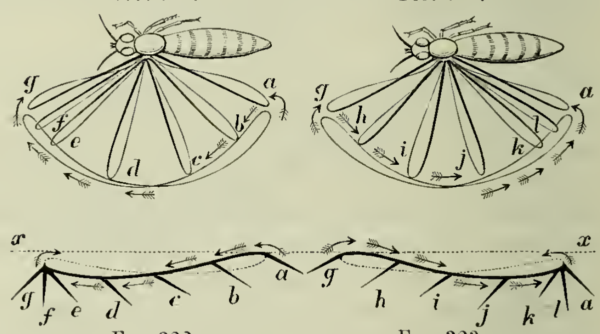


Fig. 319.—Appearance of a wasp, according to Marey, when the tips of the larger wings have been gilded and the wings are oscillating. The insect is supposed to be placed in a sunbeam. ("Animal Mechanism," 1874, p. 187, Fig. 71.)

I am at a loss to understand what Professor Marey means when he says that the crossing of the 8 would, according to me, be formed by the wing *during one of the phases of its revolution.* In my original figure-of-8, and in my description thereof, *I have invariably spoken of the two phases* of extension and flexion; extension being associated with the down stroke, and flexion with the up stroke. Professor Marey further avers that according to me "the crossing of the 8 would be formed by a complete reversal of the plane of the wing during *one of the phases* of its revolution." I have just explained that *there are two phases* in the revolution of the wing, and he cannot possibly take exception to my statement that the wing reverses its planes during extension and flexion, for he says in another part of his work (pp. 177, 188, and 195) that: "The luminous appearance given during flight by the gilded wing of an insect, shows that during the alternate movements of flight, *the plane of the wing changes its inclination* with respect to the axis of the insect's body, and that the upper surface of the wing turns a little backward during the period of ascent, whilst it is inclined forward a little during its descent." . . . "We now know all the movements executed by an insect's wing during its revolution, as well as *the double change of plane* which accompanies them." . . . "We shall find in the employment of the graphic method, *new proofs of changes in the plane of the wing* during flight. This phenomenon is of great importance, for in it we seem to find the proximate cause of the motive force which urges forward the body of the insect." (The italics are mine.)

Now as regards Professor Marey's own figures illustrating the figure-of-8 made by the wings of the insect, I venture to assert that they are in several respects inaccurate and largely imaginary. For example, he represents the wings of the wasp as making *vertical* figure-of-8 movements when the wings are made to vibrate (see annexed Fig. 319).



Figs. 320 to 323.—Show the figure-of-8 and the different angles made by the wing of the wasp with the horizon during extension and the oblique down stroke, and during flexion and the oblique up stroke. The same letters apply to all the figures. *a, b, c, d, e, f, g,* Angles made by the wing with the horizon during extension; *g, h, i, j, k, l,* angles made by the wing with the horizon during flexion; *x, x,* line of horizon. The movements of extension and flexion which are opposite movements are here recorded separately to avoid confusion. In nature the two figures to the right of the spectator would be superimposed or placed above the two figures to the left of the spectator (the Author, 1870).

The wasp, I would observe, never flies in the manner indicated in Professor Marey's figure. On the contrary, the wings of the wasp and of the majority of insects make oblique and more or less horizontal figure-of-8 movements in flying. I fully explained the oblique nature of the stroke of the insect's wing and figured it in 1867. I also pointed out that the insect reversed the plane of its wings when making the figure-of-8 movement. In 1870,[1] I described and delineated how the wasp reversed the planes of its wings during extension and flexion, at each successive down and up stroke (Figs. 320, 321, 322, and 323).

Professor Marey has curiously enough corroborated, after a considerable interval, my analysis of the more or less horizontal figure-of-8 movements, and the reversal of the planes of the wing of the insect during extension and flexion in every particular. His corroboration of my analysis is as complete as was his corroboration of my

[1] "On the Physiology of Wings." (*Transactions of the Royal Society of Edinburgh*, vol. xxvi.)

original outlined figure-of-8. I subjoin Professor Marey's figure (Fig. 324) giving details of said analysis, and it will be seen that if my Figs. 322 and 323 be superposed, as I state they would be in nature, and the compound figure compared with Professor Marey's figure (Fig. 324), no difference whatever can be detected. The figures are literal transcripts of each other. Professor Marey's figure might very well be taken for a copy of my own. It will be observed that the figure-of-8 now given by Professor Marey (Fig. 324) as representing the change of plane in the insect's wing is no longer *vertical* as in his original wasp (Fig. 319) but more or less *horizontal*, as I explained it should be.

Looking at the whole subject, I cannot help feeling that Professor Marey's ideas of the figure-of-8 movements made by the wing are exceedingly hazy, and am forced to conclude that he adopted my figure-of-8 representations of them without fully comprehending what the figure-of-8 really meant. He, moveover, endeavoured to record them piecemeal, and in fragments, by means of sphygmographic tracings, some of which he failed to interpret and did not quite understand. According to his own showing he required one set of tracings to reveal the upper loop of the 8, a second set to reveal the lower loop, and a third set to reveal the crossing of the 8. Without my original idea, the tracings would, as a matter of fact, have been equally impossible and unintelligible.

That Professor Marey owed all, or nearly all, he knew of the figure-of-8 movements made by the wing in flight to my descriptions and delineations of this knotty problem published in 1867, nearly two years before he himself wrote on the subject of flight, is evident from the following passage, which occurs at p. 234 of his book "Animal Mechanism," 1874, under the heading "Trajectory of the Wing of the Bird during Flight."

Referring to the figure-of-8 made by the insect's wing he says: "We have seen, when treating of the mechanism of insect flight, that the fundamental experiment was that which revealed to us the (figure-of-8) course of the point of the wing throughout each of its revolutions. Our knowledge of the mechanism of flight naturally flowed, if we may so say, from this first notion."

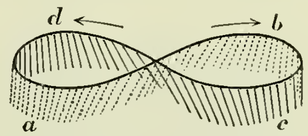


Fig. 324.—Representation of the changes in the plane of the insect's wing according to Marey. ("Animal Mechanism," 1874, p. 200, Fig. 85.)

Professor Marey agrees in the main with all I have written on the subject of flight; indeed he almost invariably follows my initiative and corroborates my views, as numerous parallel passages and illustrations in our writings will show (*vide* Appendix ii., Aerial Locomotion). He rarely, if ever, strikes out a path for himself. Nevertheless, he wishes it to be inferred that his theory of flight differs materially from mine. His rôle is largely that of the recorder of events by means of sphygmographic tracings, which in the case of the highly complex movements of animals as witnessed in locomotion are, in the majority of cases, partial, inaccurate, and misleading.

If the alternating, reversing figure-of-8 movements and curves made by the wing in extension and flexion be compared with the reversing figure-of-8 movements and curves made by the anterior and posterior portions of the fish in swimming, and the complementary figure-of-8 movements and curves made by the extremities of the biped and quadruped in walking and running, it will be seen that the several kinds of locomotion in the vertebrate series conform to a common law. It will further be seen, that the size and shape of the travelling surfaces by which locomotion is effected are, in every instance, carefully adapted to the medium to be traversed, making forethought and design practically a necessity.

The tail of the fish, the extremities of the biped and quadruped, and the wing of the bird, when moving, describe waved tracks. Thus the wing of the bird, when it is extended and flexed and made to oscillate, is thrown into double or figure-of-8 curves like the body of the fish. When, moreover, the wing ascends and descends to make the up and down strokes, it rotates within the *facettes* or depressions situated on the scapula and coracoid bones, precisely in the same way that the arm of a man rotates in the glenoid cavity, or the leg in the acetabular cavity in the act of walking. The ascent and descent of the wing in flying correspond to the steps made by the extremities in walking, the wing rotating upon the body of the bird during the down stroke, the body of the bird rotating on the wing during the up stroke. When the wing descends it describes a downward and *forward* curve, and elevates the body in an upward and *forward* curve. When the body descends, it describes a downward and *forward* curve, the wing being elevated in an upward and *forward* curve. The curves made by the wing and body in flight form, when united, waved lines, which intersect each other at every beat of the wing. The wing and the body act upon each other alternately (the one being active when the other is passive), and the descent of the wing is not more necessary to the elevation of the body than the descent of the body is, in a measure, to the elevation of the wing. It is thus that the weight of the flying animal is utilised, slip avoided, and continuity of movement secured (Fig. 325).

As to the actual waste of tissue involved in walking, swimming, and flying, there is much discrepancy of opinion. It is commonly believed that a bird exerts quite an enormous amount of power as compared with a

fish; a fish exerting a much greater power than a land animal. This, there can be no doubt, is a popular delusion. A bird can fly for a whole day, a fish can swim for a whole day, and a man can walk for a whole day. If so, the bird requires no greater power than the fish, nor the fish than the man. The speed of the bird as compared with that of the fish, or the speed of the fish as compared with that of the man, is no criterion of the power exerted. The speed is only partly traceable to the power. As has been explained, it is due in a principal measure to the shape and size of the travelling surfaces, the density of the medium traversed, the nature of the fulcrum on which the travelling organs act, the resistance experienced to forward motion, and the part performed by the mass of the animal, when moving freely in space. It is erroneous to suppose that a bird is stronger, weight for weight, than a fish, or a fish than a man. It is equally erroneous to assume that the exertions of a flying animal are herculean as compared with those of a swimming or walking animal. Observation and experiment incline me to believe just the opposite. A flying creature, when fairly launched in space (because of the part which weight plays in flight, the speed attained, and the little resistance experienced in forward motion), sweeps through the air with almost no exertion.[1] This is proved by the sailing flight of the albatross, and by the fact that some insects can fly when two-thirds of their wing area have been removed. (Original experiments by me in this connection, are detailed further on.) These observations are calculated to show the grave necessity for studying the media to be traversed; the fulcra which the media furnish, the size, shape, and movements of the travelling surfaces, the speed attained, &c. The travelling surfaces of animals, as has been explained, furnish the levers by whose instrumentality the movements of walking, swimming, and flying are effected.

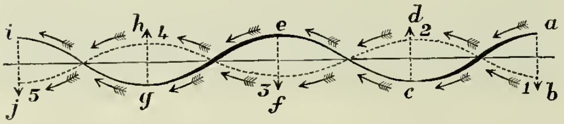


Fig. 325.—Shows the waved trajectories formed by the wings and body of a bird in flight. *a, c, e, g, i*, Waved lines formed by the descent and ascent of the wings; *b, d, f, h, j*, smaller waved line formed by the descent and ascent of the body of the bird. The body is elevated when the wings are depressed and falls when the wings are raised. The numerals from 1 to 5 indicate the down and up strokes made by the wings. The curves formed by the wings and body intersect and so furnish a figure-of-8 trajectory (the Author, 1870).

By comparing the flipper of the seal, sea-lion, and walrus with the fin and tail of the fish, whale, porpoise, &c.; and the wing of the penguin (a bird which is incapable of flight, and can only swim and dive) with the wing of the insect, bat, and bird, I have been able to show that a close analogy exists between the flippers, fins, and tails of sea mammals and fishes on the one hand, and the wings of insects, bats, and birds on the other; that theoretically and practically these organs, one and all, form flexible helices or screws, which, in virtue of their rapid reciprocating movements, operate upon the water and air by a wedge-action after the manner of twisted or double inclined planes. The twisted inclined planes act upon the air and water by means of curved surfaces, the curved surfaces reversing, reciprocating, and engendering a wave pressure, which can be continued indefinitely at the will of the animal. The wave pressure emanates in the one instance mainly from the tail of the fish, whale, porpoise, &c., and in the other from the wing of the insect, bat, or bird—*the reciprocating and opposite curves* into which the tail and wing are thrown in swimming and flying constituting *the mobile helices, or screws*, which, during their action, produce the precise kind and degree of pressure adapted to fluid media, to which they respond with the greatest readiness. Similar remarks apply to the travelling organs of bipeds and quadrupeds when walking or running on land.

In order to prove that sea mammals and fishes swim, and insects, bats, and birds fly, by the aid of curved figure-of-8 surfaces, which exert an intermittent wave pressure, I constructed artificial fish-tails, fins, flippers, and wings, which curve and taper in every direction, and which are flexible and elastic, particularly towards the tips and posterior margins. These artificial fish-tails, fins, flippers, and wings are slightly twisted upon themselves, and when applied to the water and air by a simple to-and-fro movement, or by a sculling figure-of-8 motion, curiously enough reproduce the curved surfaces and movements peculiar to real fish-tails, fins, flippers, and wings, in swimming, and flying.

Propellers formed on the fish-tail and wing model are, I find, the most effective that can be devised, whether for navigating the water or the air. To operate efficiently on fluid, or yielding media, the propeller itself must yield. Of this I am fully satisfied from observation and experiment. The propellers at present employed in navigation are, in my opinion, faulty both in principle and application.

The observations and experiments here recorded date from 1864. In 1867 I lectured on the subject of animal mechanics (more particularly, flight in relation to aeronautics), at the Royal Institution of Great Britain:[2] in June of the same year (1867) I read a memoir "On the Mechanism of Flight" to the Linnean Society of London;[3] and

[1] A flying creature exerts its greatest power when rising. The effort is of short duration, and inaugurates rather than perpetuates flight. If the volant animal can launch into space from a height, the preliminary effort may be dispensed with, as in this case the weight of the animal acting upon the inclined planes formed by the wings gets up the initial velocity. Swallows and bats often allow themselves to fall into space when beginning their aerial voyages.

[2] "On the various Modes of Flight in Relation to Aeronautics." (*Proceedings of the Royal Institution of Great Britain*, March 22, 1867.)

[3] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom." (*Transactions of the Linnean Society*, vol. xxvi.)

in August of 1870 I communicated a memoir "On the Physiology of Wings" to the Royal Society of Edinburgh.[1] These memoirs extend to 200 pages quarto, and are illustrated by 190 original drawings. The conclusions at which I arrived, after a careful study of the movements of walking, swimming, and flying, are briefly set forth in a letter addressed to the French Academy of Sciences in March 1870. This the Academy did me the honour of publishing in April of that year (1870) in the *Comptes Rendus*, p. 875. In it I claim to have been the first to describe and illustrate the following points :—

1. That bipeds and quadrupeds walk, and fishes swim, and insects, bats, and birds fly by figure-of-8 movements.

2. That the flipper of the sea-lion, the swimming wing of the penguin, and the wing of the insect, bat, and bird, are screws *structurally*, and resemble the blades of an ordinary screw-propeller.

3. That those organs are screws *functionally*, from their twisting and untwisting, and from their rotating in the direction of their length, when they are made to oscillate.

4. That they have a reciprocating action, and reverse their planes more or less completely at every stroke.

5. That the wing describes *a figure-of-8 track* in space when the flying animal is artificially fixed.

6. That the wing, when the flying animal is progressing at a high speed in a horizontal direction, describes *a looped* and then *a waved track*, from the fact that the figure-of-8 is gradually opened out or unravelled as the animal advances.

7. That the wing acts after the manner of a kite, both during the down and up strokes.

I was induced to address the letter in question to the French Academy of Sciences from finding that, *nearly two years* after I had published my views on the figure-of-8, looped, and waved movements made by the wing, &c., Professor E. J. Marey (College of France, Paris) published a series of lectures and papers in the *Revue des Cours Scientifiques de la France et de l'Étranger*,[2] and in the *Comptes Rendus hebdomadaires des Séances de l'Académie des Sciences*,[3] in which the peculiar figure-of-8 movements, first described and figured by me, were put forth as a new discovery. The accuracy of this statement will be abundantly evident when I mention that my first lecture, "On the various Modes of Flight in Relation to Aeronautics," was published in the *Proceedings of the Royal Institution of Great Britain* on the 22nd of March 1867, and translated into French (*Revue des Cours Scientifiques de la France et de l'Étranger*) on the 21st of September 1867 ; whereas Marey's first lecture, "On the Movements of the Wing of the Insect" (*Revue des Cours Scientifiques de la France et de l'Étranger*), did not appear until the 13th of February 1869.

Professor Marey in his lectures and papers made no allusion to my researches, which was the more remarkable as my first lecture on flight, referred to, appeared in the same French Journal[4] in which a lecture by him "On the Registering Instruments employed in Biology" appeared. Indeed part of his lecture occurs on the same page as that on which mine terminates.

Professor Marey, before replying to my letter addressed to the French Academy of Sciences, wrote me privately to inquire how he could reply to my "Juste reclamation," without entering into a discussion which would needlessly complicate the question. I thereupon requested him to admit in a letter addressed to the French Academy my claim to have described and illustrated before him the figure-of-8 movements made by the wings of insects, bats, and birds when those animals are artificially fixed, and of the spiral and undulating wave-tracks made by the wing of said insects, bats, and birds when the animals are flying at a high horizontal speed. This he did, as the subjoined extract from his letter to the French Academy, printed in the *Comptes Rendus* for May 16th, 1870 (p. 1093), shows. He admits my claim to priority in the following terms : "I have ascertained that in reality Mr. Pettigrew has been before me, and represented in his memoirs the figure-of-8 track made by the wing of the insect, and that the optic method to which I had recourse is almost identical with his. But we differ entirely as to the interposition of the trajectory seen by us both. I hasten to satisfy this legitimate demand, and leave entirely to Mr. Pettigrew the priority over me relatively to the question as restricted."

Professor Marey's restriction, it should be remarked, refers not to the figure-of-8 itself, but to matters of detail in which, as already explained, I believe him to be in error, and I hope to be able to show further on that notwithstanding his reservation as to our interpretation of the figure-of-8 he corroborates nearly everything I have written on the subject.

That we are substantially in agreement, and that he derived the cue to his flight researches from my original figure-of-8, is abundantly evident from his own remarks in another place,[5] where, when speaking of the "trajectory

[1] "On the Physiology of Wings." (*Transactions of the Royal Society of Edinburgh*, vol. xxvi.)

[2] "Les mouvements de l'aile chez les insectes," p. 171, 13 Février 1869. "Mécanisme du vol chez les insectes—comment se fait la propulsion," p. 252, 20 Mars 1869. "Du vol des oiseaux," p. 578, 14 Août 1869. "Du vol des oiseaux (suite)," p. 601, 21 Août 1869. "Du vol des oiseaux (suite)," p. 646, 11 Septembre 1869. "Du vol des oiseaux (fin)," p. 700, 2 Octobre 1869.

[3] "Determination expérimentale du mouvement des ailes des insectes pendant le vol." Par M. E. J. Marey. Tome lxvii., p. 1341 ; tome lxviii., p. 667.

[4] *Revue des Cours Scientifiques de la France et de l'Étranger*, 21 Septembre 1867.

[5] "Animal Mechanism." International Scientific Series, 1874, p. 234.

of the wing of the bird during flight," and, as I have already pointed out, he says : " We have seen, when treating of the mechanism of insect flight, that the fundamental experiment was that which revealed to us the (figure-of-8) course of the point of the wing throughout each of its revolutions. *Our knowledge of the mechanism of flight naturally flowed, if we may so say, from this first notion.*" (The italics are mine.) It is easy to apply recording apparatus to illustrate and verify a principle once discovered, explained, and illustrated, and this is all Professor Marey has done so far as the figure-of-8 and waved movements made by the wing are concerned. Mere mechanical corroboration, however, does not add to or take from the importance of the original discovery, neither does it establish a claim to any part of the discovery as Professor Marey seems to think.

A history of the figure-of-8 movements made in walking, swimming, and flying, especially the latter, as originally described and figured by me, is given in my memoir " On the Physiology of Wings," communicated to the Royal Society of Edinburgh on the 2nd of August 1870 (*Trans. Roy. Soc. Edin.*, vol. xxvi.). I may also direct attention to an appreciative article on my flight researches and claims to priority, as regards the figure-of-8 and waved movements made by the wing, published by Professor Coughtrie in the *Quarterly Journal of Science* for April 1875, with the title, " Pettigrew *versus* Marey." In the article in question Professor Coughtrie gives dates and parallel passages which explain themselves and may interest the reader. The passages in question are numerous and important, and establish priority, not in one, but in many directions. The coincidences in the passages as to facts are, to say the least, very striking, especially when priority of discovery is taken into account. Professor Coughtrie's article forms Appendix ii. of the present work.

The figure-of-8 theory of flying, originally propounded by me in the lecture, papers, and memoirs referred to, has been confirmed not only by the researches and experiments of Professor Marey, but also by those of M. Senecal, M. de Fastes, M. Ciotti, and others. Its accuracy is no longer a matter of doubt.

Before leaving this subject, it seems necessary to re-affirm that the restriction made by Professor Marey, of which he has made so much, was, in reality, based upon an erroneous and inaccurate interpretation of my descriptions and drawings of the figure-of-8 and waved movements made by the wings, originally published in the twenty-sixth volume of the *Transactions of the Linnean Society of London.* Professor Marey also greatly blundered as to the figure-of-8 spiral movements made in locomotion generally, and as to the screw configuration and function of the travelling organs of animals as a whole.

In speaking of the curves made by the wing which I was the first to describe and delineate [1] (Figs. 306 to 313 inclusive), he says : " If we take a dead bird, and spread out its wings, we see that at different points in its length the wing presents very remarkable changes of plane. At the inner part, towards the body, the wing inclines considerably both downwards and backwards, while near its extremity, it is horizontal and sometimes slightly turned up, so that its under surface is directed somewhat backward. Dr. Pettigrew thought that he could find in this curve a surface resembling a left-handed screw propeller : struck with the resemblance between the form of the wing and that of the screw used in navigation, he considered the wing of a bird as a screw of which the air formed the nut. We do not think that we need refute such a theory. It is too evident that the alternating type which belongs to every muscular movement cannot tend to produce the propulsive action of a screw ; for while we admit that the wing revolves on an axis, this rotation is confined to the fraction of a turn, and is followed by rotation in the opposite direction, which in a screw would entirely destroy the effect produced by the previous movement. And yet the English writer to whose ideas we refer has been so fully convinced of the truth of his theory that he has wished to extend it to the whole animal kingdom. He proposes to refer locomotion in all its forms, whether terrestrial, aquatic, or aerial, to the movements of a screw propeller." [2]

In reply to Professor Marey's remarks quoted above, I have to observe that it required not even a rudimentary knowledge of anatomy to realise that wings, fins, fish-tails, and the travelling organs of animals could not be made to rotate *continuously* as the screw propeller of a ship does. Their attachment to the bodies to which they belong forbids this. They can, nevertheless, perform well-marked rotatory screw movements. The wing of the bird during flexion and extension, and in certain movements, can rotate from anything up to and over a quarter of a turn ; and the forearm and hand in man during pronation and supination, aided by circumduction, can make quite three-quarters of a turn. The travelling organs of the higher animals are certainly screws structurally and act as such functionally. A glance at the extremities of the skeleton of the biped and quadruped will settle the structural point, and a cursory study of the movements of the extremities during life will settle the functional point. The difference between the screw propeller of a ship and the travelling organs of animals consists mainly in this : (*a*) the propeller is rigid, and the travelling organs are elastic ; and (*b*) the travelling organs, as I was careful to point out, form reversing reciprocating screws, that is, they do not rotate always in one and the same direction. This,

[1] *Transactions of the Linnean Society, London*, vol. xxvi., pp. 248, 249 (read to the Society, June 6 and 20, 1867).
[2] " Animal Mechanism : a Treatise on Terrestrial and Aerial Locomotion," by Professor E. J. Marey. London, 1874, pp. 210, 211.

however, does not vitiate the fact, that the travelling organs are screws structurally and functionally. The peculiarity of the travelling organs consists in their alternately suddenly seizing and letting go (after the manner of screws) the earth, water, and air which form their fulcra.

This double power the propeller also possesses. When driven in one direction it causes the ship to forge ahead, when driven in another and opposite direction the vessel is made to sail stern first. The same is true of an ordinary screw-nail. When projected into timber by the aid of a screw-driver in one direction the screw-nail bites, jams, and becomes fixed as it is screwed home. When the screw-driver is made to act in an opposite direction the screw-nail lets go and extricates itself from the timber. It can be made to seize and let go the timber alternately, precisely as the travelling organs do. This is its chief merit, as it is that of the screw propeller. Both possess a double power. They can be made to reciprocate and act in diametrically opposite directions without ceasing to be screws. The same is true of the auger and gimlet. This is exactly what happens in the travelling organs of the higher animals in locomotion. They are applied as reversing reciprocating screws to the earth, water, and air which form their objectives or fulcra. The sinuous gliding movements of the screw are, mechanically speaking, the most perfect that can be devised for the purposes of locomotion.

It is necessary to state, in this connection, that Professor Marey, intentionally or unintentionally, has always misinterpreted and misrepresented my views as regards animal locomotion, and I am compelled to record the opinion, that he either did not know, or wilfully ignored the fact, that the bones forming the spinal column, scapulæ, and pelvis, and the extremities of bipeds and quadrupeds, and their joints, are each and all spiral in their nature, and that the muscles of the trunk and extremities are spirally adapted to the bones, making the figure-of-8 screwing movements, to which I have directed attention, not a matter of accident but of design and necessity. His methods of recording the spiral, screw, and other movements referred to, as the results obtained by him in his "Animal Mechanism," 1874, conclusively proved, were wholly inadequate.

In order to be fully convinced that the anterior and posterior extremities of the higher animals rotate in the direction of their length, and twist and plait to form diagonal figure-of-8 curves, one has only to examine instantaneous photographs of quadrupeds, birds, and men walking. These photographs reproduce the actual movements, not piecemeal, but in their totality; they give the movements not only of the parts but of the whole animal. Such results could not possibly be obtained by any form of mechanical registering apparatus, however extensive and complicated. The sphygmograph is a crude and unreliable instrument when called upon to register the subtleties of locomotion where many parts are moving at the same instant, and where the movements imperceptibly and rapidly glide into each other. Aided and guided by instantaneous photography we can see that the spiral figure-of-8 movements made by the limbs in bipeds and quadrupeds are due, in part, to the diagonal spiral twisting movements occurring at the shoulders and hips. As a matter of fact, the figure-of-8 movements of the limbs primarily emanate from the trunk. In the same way that the limbs are to be regarded as buds or offshoots from the trunk, so the figure-of-8 movements of the limbs are to be regarded as repetitions of similar movements occurring in the trunk itself. (See Figs. 326 to 333.)

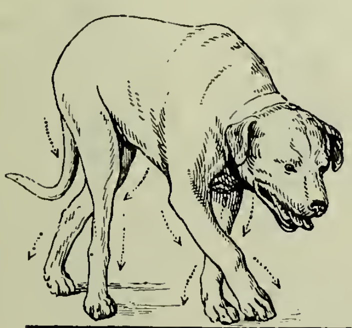


FIG. 326.

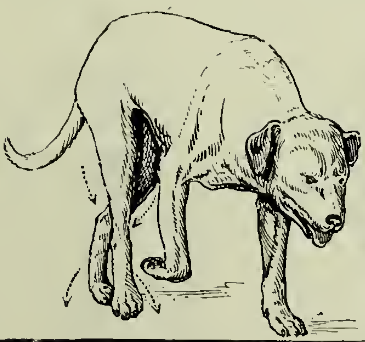


FIG. 327.

FIG. 328.

FIG. 329.

FIG. 326.—Shows the twisting and plaiting in both the anterior and posterior extremities (*vide* darts) of a mastiff dog when walking.

FIG. 327.—Shows the same thing in the hind legs.

FIG. 328.—Shows the plaiting in both the anterior and posterior extremities of the tiger when walking.

FIG. 329.—Shows the same thing in the fore legs.

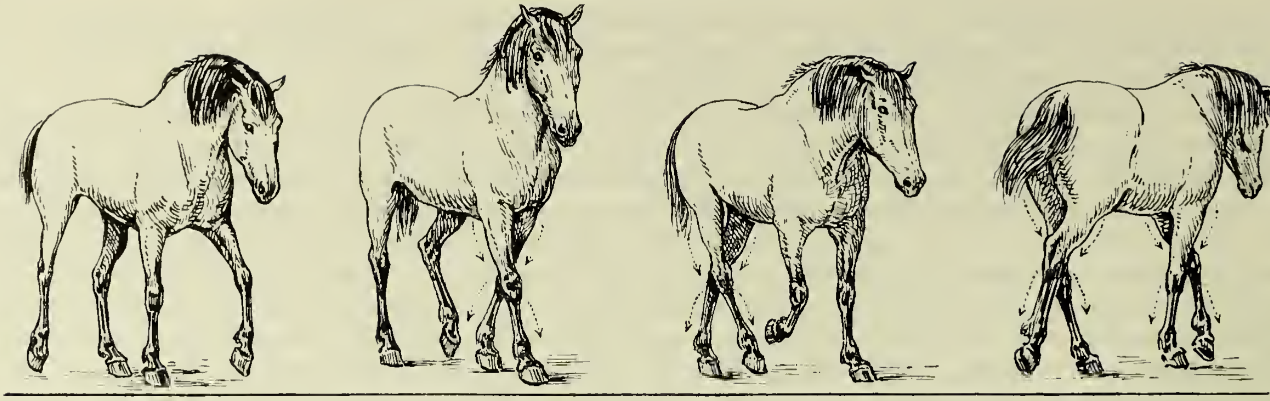


FIG. 330. FIG. 331. FIG. 332. FIG. 333.

FIG. 330.—Shows the ordinary walk of a horse with the legs apart before the plaiting begins
FIG. 331.—Shows the plaiting (*vide* darts) in the fore legs.
FIG. 332.—Shows the plaiting in the hind legs.
FIG. 333.—Shows the plaiting in both the fore and hind legs.

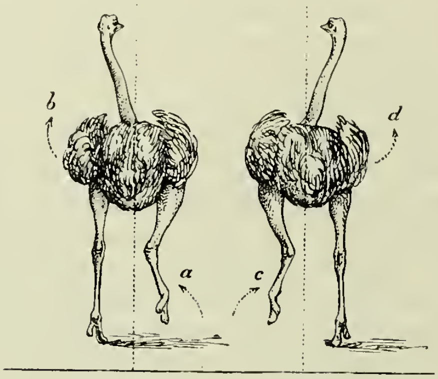


FIG. 334. FIG. 335.

FIG. 336. FIG. 337.

FIGS. 334 and 335 show the diagonal, reversing, spiral curves made by the right leg (*a*), and left shoulder (*b*), and by the left leg (*c*), and right shoulder (*d*) of the ostrich in running, as seen from behind. The darts indicate the direction of movement. When the right leg is flexed and raised from the ground the right shoulder is elevated (Fig. 334). When the left leg is flexed and raised from the ground, the left shoulder is elevated (Fig. 335). The elevation of the right and left shoulders coincides with the flexing and elevating of the right and left legs and feet.

FIGS. 336 and 337.—Anterior and posterior views of a nude female walking. Show the twisting and overlapping of the inferior extremities at each step as indicated by the diagonal, curved darts.

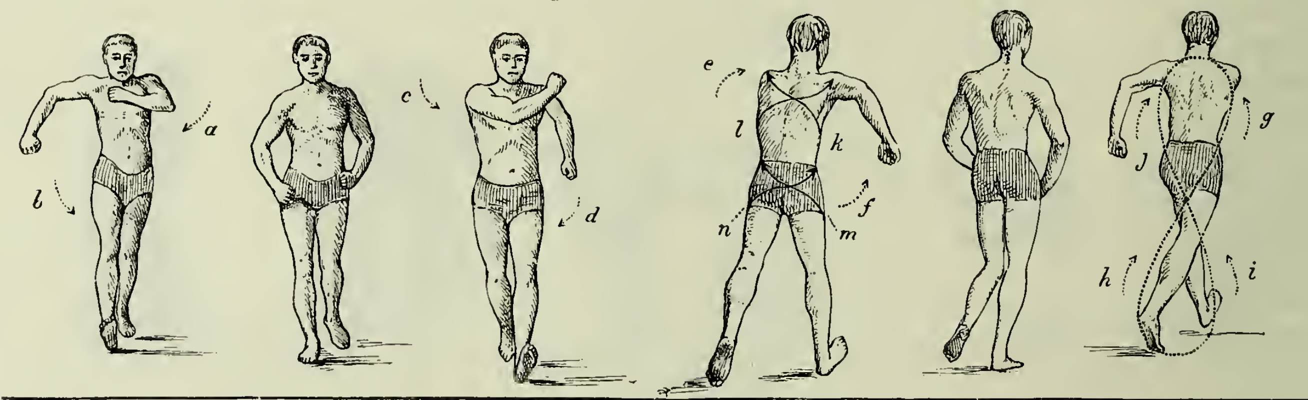


FIG. 338.

FIG. 338.—Instantaneous photographs of a man walking at a brisk pace, seen from before and behind. Show the double figure-of-8 curves made by the superior and inferior extremities, and the double twisting movements which occur at the shoulders and hips in walking. At Fig. 1, the left arm (*a*) and right leg (*b*) advance together in curves (see darts) to make one step. At Fig. 3, the right arm (*c*) and left leg (*d*) advance together in curves (see darts) to make a second step. The same movements are seen at Fig. 302, p. 1078, where the interrupted line represents the curves made by the arms in walking; the continuous line representing those made by the legs. The twisting movements which occur at the shoulders and hips in walking are seen at *k*, *l* and *m*, *n* (see darts); those made by the legs and arms at *h*, *i* and *j*, *g*. These are figure-of-8 movements. In the central figures the extremities are in the act of reversing.

In Fig. 336 (anterior view) the right leg is leading and making the step. It is plaiting over and round the left leg (see curved darts running from right to left).

In Fig. 337 (posterior view) the left leg is leading and making the step. It is plaiting over and round the right leg (see curved darts running from left to right).

The plaiting in question is, as previously indicated, the outcome of the spiral bones, spiral muscles, spiral joints, the pendulum movements of the extremities, permitted by the ball-and-socket joints, and the fundamental diagonal screwing movements which occur at the hips.

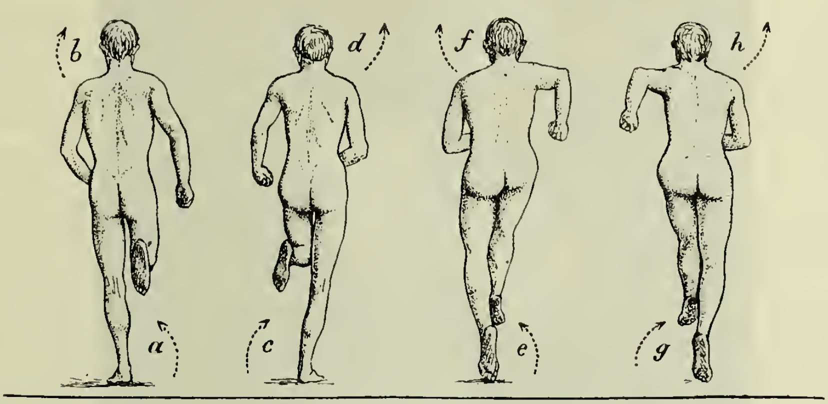


Fig. 339.—Nude man running as seen from behind. Shows that in running, as in walking, a diagonal spiral wave of motion runs alternately from right to left (see curved darts *a*, *b* and *e*, *f*) and from left to right (see curved darts *c*, *d*, and *g*, *h*) at each successive step. The diagonal twisting, screwing movements can only be accomplished by primary or preliminary screwing movements occurring at the shoulders and hips.

In the famous statue known as the Venus of Milo, the cross diagonal movements, the raising of the shoulder, the flexing of the limb on the same side, and the simultaneous advance of an arm and leg on opposite sides of the body are seen to perfection. This, the most graceful and powerful of all the Grecian works of art, must have been taken from the life and by a master who at once knew his anatomy and his physiology. It is too accurate and too realistic to be the product of the imagination.

I have been fortunate enough to secure a remarkably fine photograph of this celebrated work of antiquity taken from the marble itself in the Louvre, Paris, which I here reproduce (Fig. 340).

The Venus of Milo, it will be seen, is a wonderful embodiment of all that is graceful, tender, and lovely in woman. Everywhere there is beauty. The curves, which are exquisite in themselves, run into each other in soft flowing lines, making it difficult to say where they begin and where they terminate. There are no hardness, no angles. Everything is rounded off as if water had flowed over and given the finishing touches to the marble. All is sweetness, dignity, and power. A veritable line of beauty marks the mesial line of the figure—a double curve, a wave, an elongated letter S, a half figure-of-8. The head, elegant, benign, thoughtful, and finely poised, is inclined to the right side, the right shoulder is lowered, what remains of the right arm projecting forwards in a curve. The right leg is extended with the right foot placed on the ground. The left shoulder is raised and the left leg flexed and projecting forwards in a curve. The right arm and left leg form opposite complementary curves and give to the figure its wonderfully graceful outlines; the position of the limbs necessitating a diagonal screwing or twisting of the trunk at the shoulders and hips, which for subtlety, grace, expression, and strength cannot be equalled, far less surpassed. The pose of the figure is simply inimitable.

The head, neck, and chest bend gracefully to the right, while the loins, pelvis, and left thigh bend gracefully to the left. The figure is twisted upon itself. Here the lines and curves of beauty are at their best. The right shoulder and hip are depressed; the left shoulder and hip elevated; the remains of the right arm and the left leg are projecting forwards in curves, the latter being flexed. The root of the left arm and the right leg are directed backwards; the latter being extended. There is no repetition anywhere. Of this, the finest of all the Venuses, it may truly be affirmed, as of Cleopatra,

> "Age cannot wither her, nor custom stale
> Her infinite variety."

The head and neck, the shoulders, the chest, the loins, the pelvis, the limbs are characterised by a simplicity, a sweetness, and a restfulness all their own. Every part of the figure is bi-laterally symmetrical, and yet there is everywhere difference. This is the very essence and soul of art, to wit, variety in sameness or in a commonly

accepted ideal. The drapery on the lower part of the figure is so delicately chiselled that some parts of it almost seem transparent. This is especially true of the drapery covering the left leg.

While I might readily have expatiated at great length on this noble creation of Grecian genius, I feel I would not have been true to nature and art if I had said less.

As the limits of the present portion of the work will not admit of my going into the several arrangements by

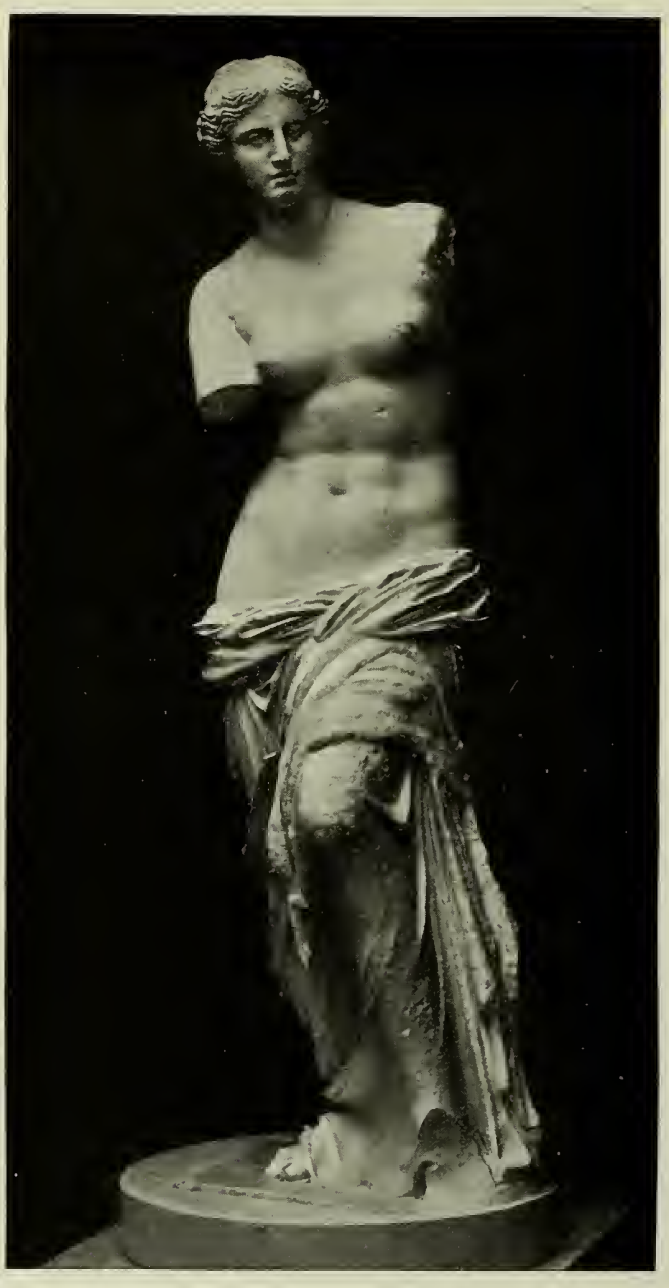


FIG. 340.—Photograph of the celebrated Venus of Milo from the original marble. Shows the exquisite double curve (line of beauty) made by the head, neck, body and limbs, and how the right arm and left leg are screwed forwards—the left arm and right leg occupying a posterior position (the Author).

which locomotion is attained in the animal kingdom as a whole, I will confine myself to generalities, and only describe those movements which illustrate in a progressive manner the several kinds of progression on the land, and on and in the water and air. I the more readily adopt this course as I take up in detail, in subsequent pages, the subjects of walking, swimming, and flying under separate headings.

I propose here to analyse the natural movements of walking, swimming, and flying. Certain of these movements may be reproduced artificially, and an account of them is given in the concluding section of the work. They are mainly connected with aerostation. The locomotion of animals depends upon mechanical adaptations found

in all such as change locality. These adaptations are very various, but under whatever guise they appear they are substantially those to which we resort when we wish to move bodies artificially. Thus in animal mechanics we have to consider the various orders of levers, the pulley, the centre of gravity, specific gravity, the resistance offered by solids, semi-solids, fluids, &c. As the laws which regulate the locomotion of animals are essentially those which regulate the motion of bodies in general, it will be necessary to consider briefly at this stage the properties of matter when at rest and when moving. They are well stated by Mr. Bishop in a series of propositions which I take the liberty of transcribing :—

§ 329. "**Fundamental Axioms.**—First, every body continues in a state of rest, or of uniform motion in a right line, until a change is effected by the agency of some mechanical force. Secondly, any change effected in the quiescence or motion of a body is in the direction of the force impressed, and is proportional to it in quantity. Thirdly, reaction is always equal and contrary to action, or the mutual actions of two bodies upon each other are always equal and in opposite directions.

§ 330. "**Of Uniform Motion.**—If a body moves constantly in the same manner, or if it passes over equal spaces in equal periods of time, its motion is uniform. The velocity of a body moving uniformly is measured by the space through which it passes in a given time.

"The velocities generated or impressed on different masses by the same force are reciprocally as the masses.

§ 331. "**Motion Uniformly Varied.**—When the motion of a body is uniformly accelerated, the space it passes through during any time whatever is proportional to the square of the time.

"In the leaping, jumping, or springing of animals in any direction (except the vertical), the paths they describe in their transit from one point to another in the plane of motion are parabolic curves.

§ 332. "**The Legs move largely as Pendulums owing to the Force of Gravitation.**—The Professors Weber have ascertained, that when the legs of animals swing forward in progressive motion, they obey the same laws as those which regulate the periodic oscillations of the pendulum.

§ 333. "**Resistance of Fluids.**—Animals moving in air and water experience in those media a sensible resistance, which is greater or less in proportion to the density and tenacity of the fluid, and the figure, superficies, and velocity of the animal.

"An inquiry into the amount and nature of the resistance of air and water to the progression of animals will also furnish the data for estimating the proportional values of those fluids acting as fulcra to their locomotive organs, whether they be fins, wings, or other forms of lever.

"The motions of air and water, and their directions, exercise very important influences over velocity resulting from muscular action.

§ 334. "**Mechanical Effects of Fluids on Animals immersed in them.**—When a body is immersed in any fluid whatever, it will lose as much of its weight relatively as is equal to the weight of the fluid it displaces. In order to ascertain whether an animal will sink or swim, or be sustained without the aid of muscular force, or to estimate the amount of force required that the animal may either sink or float in water, or fly in the air, it will be necessary to have recourse to the specific gravities both of the animal and of the fluid in which it is placed.

"The specific gravities or comparative weights of different substances are the respective weights of equal volumes of those substances.

§ 335. "**Centre of Gravity—the Lever—its Relation to Stability.**—The centre of gravity of any body is a point about which, if acted upon only by the force of gravity, it will balance itself in all positions ; or, it is a point which, if supported, the body will be supported, however it may be situated in other respects ; and hence the effects produced by or upon any body are the same as if its whole mass were collected into its centre of gravity.

"The attitudes and motions of every animal are regulated by the positions of their centres of gravity, which, in a state of rest, and not acted upon by extraneous forces, must lie in vertical lines which pass through their basis of support.

"In most animals moving on solids, the centre is supported by variously adapted organs ; during the flight of birds and insects it is suspended ; but in fishes, which move in a fluid whose density is nearly equal to their specific gravity, the centre is acted upon equally in all directions." [1]

[1] "Cyc. of Anat. and Phy.," Art. "Motion," by John Bishop, Esq.

As the locomotion of the higher animals, to which my remarks more particularly apply, is in all cases effected by levers which differ in no respect from those employed in the arts, it may be useful to allude to them in a passing way. This done, I will consider the bones and joints of the skeleton which form the levers, and the muscles which move them.

§ 335 (*a*). **The Lever.**—Levers are commonly divided into three kinds, according to the relative positions of the prop or fulcrum, the power, and the resistance or weight. The straight lever of each order is equally balanced when the power multiplied by its distance from the fulcrum equals the weight, multiplied by its distance, or P the power, and W the weight, are in equilibrium when they are to each other in the inverse ratio of the arms of the lever, to which they are attached. The pressure on the fulcrum, however, varies.

In straight levers of the *first kind*, the fulcrum is between the power and the resistance, as in Fig. 341, where

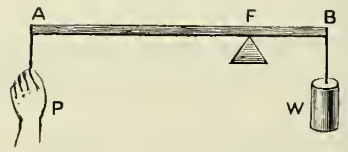


Fig. 341.

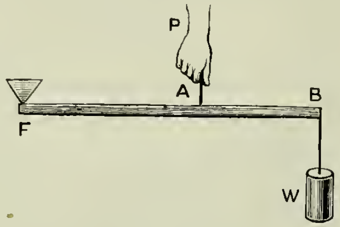


Fig. 342.

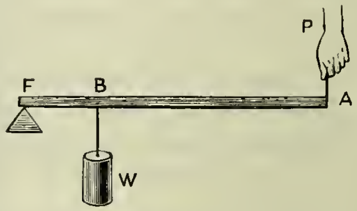


Fig. 343.

F is the fulcrum of the lever AB ; P is the power, and W the weight or resistance. We have $P : W :: BF : AF$, hence $P . AF = W . BF$, and the pressure on the fulcrum is both the power and resistance, or $P + W$.

In the second order of levers (Fig. 342), the resistance is between the fulcrum and the power; and, as before, $P : W :: BF : AF$, but the pressure of the fulcrum is equal to $W - P$, or the weight less the power.

In the third order of lever the power acts between the prop and the resistance (Fig. 343), where also $P : W :: BF : AF$, and the pressure on the fulcrum is $P - W$, or the power less the weight.

In the preceding computations the weight of the lever itself is neglected for the sake of simplicity, but it obviously forms a part of the elements under consideration, especially with reference to the arms and legs of animals.

To include the weight of the lever we have the following equations : $P . AF + \overline{AF} . \frac{1}{2} AF = W . BF + \overline{BF} . \frac{1}{2} BF$; in the first order, where $\overline{AF}$ and $\overline{BF}$ represent the weights of these portions of the lever respectively. Similarly, in the second order, $P . AF = W . BF + \overline{AF} . \frac{AF}{2}$; and in the third order, $P . AF = W . BF + \overline{BF} . \frac{BF}{2}$.

In this outline of the theory of the lever, the forces have been considered as acting vertically, or parallel to the direction of the force of gravity.

PASSIVE ORGANS OF LOCOMOTION

§ 336. **Bones.**—" The solid framework or skeleton of animals which supports and protects their more delicate tissues, whether chemically composed of entomoline, carbonate, or phosphate of lime ; whether placed internally or externally ; or whatever may be its form or dimensions, presents levers and fulcra for the action of the muscular system, in all animals furnished with earthy solids for their support, and possessing locomotive power." [1] The levers and fulcra are well seen in the extremities of the deer, the skeleton of which is selected for its extreme elegance (Fig. 344).

While the bones of animals form levers and fulcra for portions of the muscular system, it must never be forgotten that the earth, water, and air form fulcra for the travelling surfaces of animals as a whole. Two sets of fulcra are therefore always to be considered, namely, those represented by the bones, and those represented by the earth, water, or air respectively. The former when acted upon by the muscles produce motion in different parts of the animal (not necessarily progressive motion) ; the latter when similarly influenced produce locomotion. Locomotion is greatly favoured by the tendency which the body once set in motion has to advance in a straight line. The form, strength, density, and elasticity of the skeleton varies in relation to the bulk and locomotive power of the animal, and to the media in which it is destined to move.

" The number of movable articulations in a skeleton determines the degree of its mobility within itself ; and

[1] Bishop, op. cit.

the kind and number of the articulations of the locomotive organs determine the number and disposition of the muscles acting upon them.

"The bones of vertebrated animals, especially those which are entirely terrestrial, are much more elastic, hard, and calculated by their chemical elements to bear the shocks and strains incident to terrestrial progression, than those of the aquatic vertebrata; the bones of the latter being more fibrous and spongy in their texture, the skeleton is more soft and yielding."

The bones of the higher orders of animals are constructed according to the most approved mechanical principles. Thus they are convex externally, concave within, and strengthened by ridges running across their discs, as in the scapular and iliac bones; an arrangement which affords large surfaces for the attachment of the powerful muscles of locomotion. The bones of birds in many cases are not filled with marrow but with air—a circumstance which insures that they shall be very strong and very light.

In the thigh bones of most animals an angle is formed by the head and neck of the bone with the axis of the body, which prevents the weight of the superstructure coming vertically upon the shaft, converts the bone into an elastic arch, and renders it capable of supporting the weight of the body in standing, leaping, and in falling from considerable altitudes.

§ 336 (*a*). **Joints.**—"Where the limbs are designed to move to and fro simply in one plane, the ginglymoid or hinge-joint is employed; and where more extensive motions of the limbs are requisite, the enarthrodial, or ball-and-socket joint, is introduced. These two kinds of joints predominate in the locomotive organs of the animal kingdom.

"The enarthrodial joint has by far the most extensive power of motion, and is therefore selected for uniting the limbs to the trunk. It permits of the several motions of the limbs termed pronation, supination, flexion, extension, abduction, adduction, and rotation upon the axis of the limb or bone about a conical area, whose apex is the axis of the head of the bone, and base circumscribed by the distal extremity of the limb."[1]

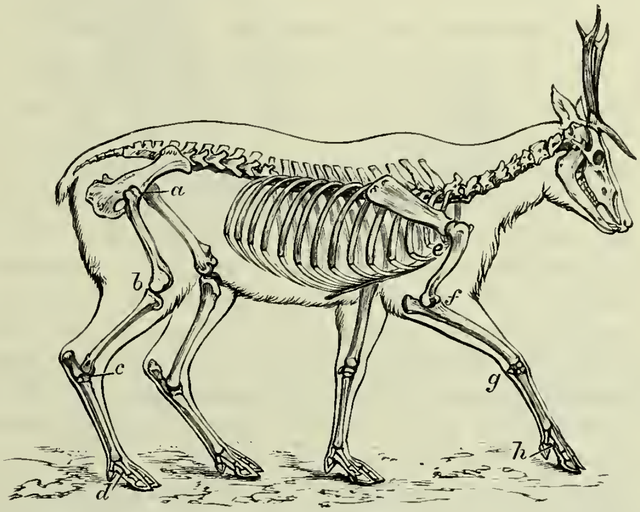


Fig. 344.—Skeleton of the deer. The bones in the extremities of this the fleetest of quadrupeds are inclined very obliquely towards each other, and towards the scapular and iliac bones. This arrangement increases the leverage of the muscular system and confers great rapidity on the moving parts. It augments elasticity, diminishes shock, and indirectly begets continuity of movement. *a*, Angle formed by the femur with the ilium; *b*, angle formed by the tibia and fibula with the femur; *c*, angle formed by the cannon bone with the tibia and fibula; *d*, angle formed by the phalanges with the cannon bone; *e*, angle formed by the humerus with the scapula; *f*, angle formed by the radius and ulna with the humerus; *g*, angle formed by the cannon bone with the radius and ulna; *h*, angle formed by the phalanges with the cannon bone (after Pander and D'Alton).

The ginglymoid or hinge-joints are for the most part spiral in their nature. They admit in certain cases of a limited degree of lateral rocking. Much attention has been paid to the subject of joints (particularly human ones) by the brothers Weber, Professor Meyer of Zürich, and likewise by Langer, Henke, Meissner, and Goodsir. Langer, Henke, and Meissner succeeded in demonstrating the "screw configuration" of the articular surfaces of the elbow, ankle, and calcaneo-astragaloid joints, and Goodsir showed that the articular surfaces of the knee-joint consist of "a double conical screw combination." The last-named observer also expressed his belief "that articular combinations with opposite windings on opposite sides of the body, similar to those in the knee-joint, exist in the ankle and tarsal, and in the elbow and carpal joints; and that the hip and shoulder joints consist of single threaded couples, but also with opposite windings on opposite sides of the body." I have succeeded in demonstrating a similar spiral configuration in the several bones and joints of the wing of the bat and bird, and in the extremities of most quadrupeds. The bones of animals, particularly the extremities, are, as a rule, twisted levers, and act after the manner of screws. This arrangement enables the higher animals to apply their travelling surfaces to the media on which they are destined to operate at any degree of obliquity so as to obtain a maximum of support or propulsion with a minimum of slip. If the travelling surfaces of animals did not form screws structurally and functionally, they could neither seize nor let go the fulcra on which they act with the requisite rapidity to secure speed, particularly in water and air.

[1] Bishop, op. cit.

§ 336 (*b*). "**Ligaments.**—The function of the ligaments with respect to locomotion, is to restrict the degree of flexion, extension, and other motions of the limbs within definite limits.

§ 337. "**Effect of Atmospheric Pressure on Limbs.**—The influence of atmospheric pressure in supporting the limbs was first noticed by Dr. Arnott, though it has been erroneously ascribed by Professor Müller to Weber. Subsequent experiments made by Dr. Todd, Mr. Wormald, and others, have fully established the mechanical influence of the air in keeping the mechanism of the joints together. The amount of atmospheric pressure on any joint depends upon the area or surface presented to its influence, and the height of the barometer. According to Weber, the atmospheric pressure on the hip joint of a man is about 26 lbs. The pressure on the knee joint is estimated by Dr. Arnott at 60 lbs." [1]

ACTIVE ORGANS OF LOCOMOTION

§ 338. Muscles, their Properties, Arrangement, Mode of Action, &c.

If time and space had permitted, I would have considered it my duty to describe, more or less fully, the muscular arrangements of all the animals whose movements I propose to analyse. This is the more desirable, as the movements exhibited by animals of the higher types are directly referable to changes occurring in their muscular system. As, however, I could not hope to overtake this task within the limits prescribed for the present work, I shall content myself by merely stating the properties of muscles ; the manner in which muscles act ; and the manner in which they are grouped, with a view to moving the osseous levers which constitute the bony framework or skeleton of the animals to be considered. Hitherto, and by common consent, it has been believed, that whereas a flexor muscle is situated on one aspect of a limb, and an extensor on the other aspect, these two muscles must be opposed to and antagonise each other. This belief is founded on what I regard as an erroneous assumption, namely, that muscles have only the power of shortening, and that when one muscle, say the flexor, shortens, it must drag out and forcibly elongate the corresponding extensor, and the converse. This would be a mere waste of power. Nature never works against herself. Moreover, muscular fibres which are made to contract artificially relax and elongate when left to themselves. There are good grounds for believing, as I have stated elsewhere,[2] that there is no such thing as antagonism in muscular movements ; the several muscles known as the flexors and extensors, abductors and adductors, pronators and supinators, &c., always acting together simultaneously, and being complemental, correlated, and conditioned.

The prevailing theory of muscular action is wholly at variance with the movements which are known to take place in the involuntary muscles, such as the heart, stomach, bladder, and uterus. In these viscera, the muscular fibres run in longitudinal, slightly oblique, oblique, and more or less transverse spiral directions ; each fibre and set of fibres having complemental or opposing fibres which everywhere balance and cross each other. Here there are what, according to accepted views, would be typical, antagonistic muscular arrangements ; yet, when the viscera open and close, which they do continually, the complemental or opposing fibres do not contend with and drag out their so-called antagonists. On the contrary, the various sets of fibres act consentaneously and harmoniously ; all the fibres displaying centrifugal movements when the viscera are to be opened, and centripetal ones when they are to be closed. In no instance do the fibres on one side of the viscera contend with those on the opposite side. That the centrifugal and centripetal movements of muscles are spontaneous and independent is proved by the action of the hollow viscera, especially those with sphincters (stomach, bladder, &c.). The sphincters cannot be forcibly opened by the contractions of the bodies of the viscera. Neither can the thick, powerful ventricles of the heart be forcibly opened by the contraction of the thin auricles. The sphincters and ventricles must relax and open of themselves. This argument is entitled to great consideration, from the fact that the involuntary muscular fibres are, in a sense, the parents of the voluntary ones both as regards structure and function. The voluntary muscles, when they act, operate upon bones or something extraneous to themselves, and not upon each other. These muscles are folded round the extremities and trunks of animals with a view to operating in masses. For this purpose they are arranged in cycles ; the extensor, abductor, and pronator muscles forming one half of the cycles, the flexors, adductors, and supinators the other.

Within these muscular cycles the bones, or extraneous substances to be moved, are placed, and when one side of a cycle shortens, the other side elongates ; the shortening and elongating movements occurring simultaneously

[1] Bishop, op. cit.

[2] "Lectures on the Physiology of the Circulation in Plants, in the Lower Animals, and in Man." (*Edinburgh Medical Journal* for January and February 1873.)

and independently. Muscles (as indicated) possess the double power of closing and opening, or what is the same thing, of shortening or contracting, and of elongating or relaxing. In other words, muscles are endowed with independent centripetal and centrifugal movements. The centripetal and centrifugal action of muscle is well illustrated by the movements of the mechanical arrangement known as lazy tongs, where there is change of shape without either increase or diminution of substance (Fig. 345 A, B).

The muscular cycles are placed at every degree of obliquity and even at right angles to each other, but they

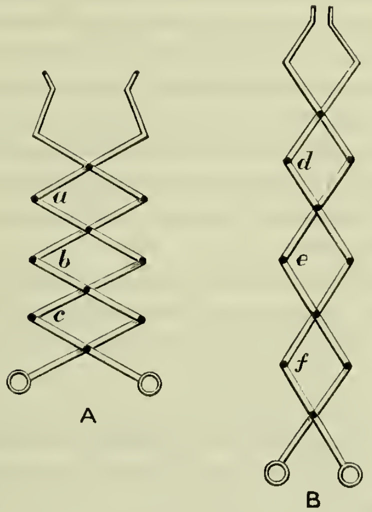


Fig. 345.

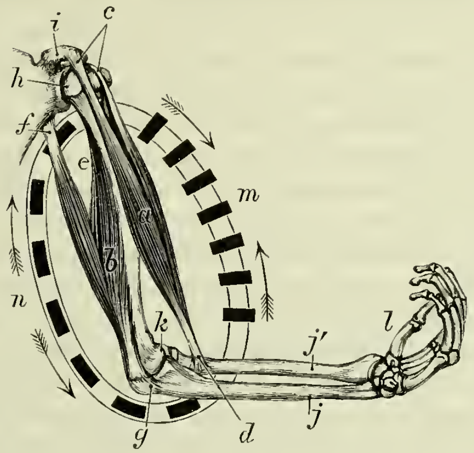


Fig. 346.

Fig. 345.—A, B, illustrate the centripetal (A) and centrifugal (B) action of muscle, and how a muscle, say an extensor, shortens (A) when the flexor elongates (B), and *vice versâ*. This figure also illustrates how the angles made by the bones of the extremities with each other in locomotion are diminished and the limb flexed or shortened (A, *a*, *b*, *c*), and how they are increased and the limb extended or elongated (B, *d*, *e*, *f*). The flexion and extension of the limbs are a *sine quâ non* in the locomotion of all the higher animals (the Author, 1872).

Fig. 346.—Shows muscular cycle formed by the biceps (*a*) and triceps (*b*) of the human arm. The forearm is half flexed on the arm ; the flexion being caused by the simultaneous, centripetal shortening action of the biceps (see darts *m*) and the corresponding centrifugal elongating action of the triceps (see darts *n*). In the biceps the sarcous elements (*m*) are elongating transversely : the muscle as a whole shortening or contracting. In the triceps the sarcous elements (*n*) are elongating longitudinally : the muscle, as a whole, lengthening or relaxing.

When the forearm is extended everything is reversed ; the sarcous elements of the biceps in this case elongating longitudinally, while the sarcous elements of the triceps elongate transversely. One side of the muscular cycle closes while the other opens both in flexion and extension, but the biceps does not drag out the triceps in flexion, neither does the triceps drag out the biceps in extension. The biceps and triceps move spontaneously and synchronously, and regulate the movements of the forearm with the greatest precision.

The present figure shows how the bones of the extremities form levers, how the levers are placed within muscular cycles, and how the angles formed by any two or more bones are increased or diminished by muscular action, which supplies the moving power. In flexion, the forearm is elevated by *decreasing* the angle formed by the humerus with the radius and ulna ; in extension, the forearm is lowered by *increasing* the angle between the bones in question. This increase and diminution of the angles formed by the bones of the extremities in extension and flexion alternately elongate and shorten the limbs and make locomotion possible. *a*, Biceps with its two heads (*c*), the one arising from the coracoid process (*i*) of the scapula ; the other from the upper margin of the glenoid cavity of the scapula ; *d*, tendon of the biceps inserted into the posterior margin of the tuberosity of the radius (*j′*) ; *e*, the three heads of the triceps, two arising from the posterior surface of the humerus, and the third from the lower part of the glenoid cavity and inferior border of the scapula (*f*) ; *g*, tendon of the triceps inserted into the posterior and upper part of the olecranon of the ulna ; *h*, head of humerus in situ within the glenoid cavity of the scapula ; *i*, coracoid process of the scapula ; *j*, ulna ; *j′*, radius ; *k*, elbow joint ; *l*, hand, flexed on the forearm ; *m*, half of muscular cycle formed by the biceps (*a*), in a state of contraction ; the sarcous elements of the muscle exhibiting a centripetal cross, or shortening action (*vide* darts) ; *n*, half of muscular cycle formed by the triceps (*b*), in a state of relaxation ; the sarcous elements of the muscle exhibiting a centrifugal, longitudinal, or elongating action (*vide* darts) (the Author, 1872).

are so disposed in the bodies and limbs of animals that they always operate consentaneously and in harmony (Fig. 346).

The bones and joints, it may be remarked, are not necessary to locomotion. In the protozoa or cell-animals this is effected by an amorphous contractile and expansile mass ; in the worm, leech, and caterpillar by imperfect muscular fibres *continuous upon themselves*, as in the hollow viscera of vertebrates. The muscle becomes interrupted in the crustaceans by the interposition of an external, and in the vertebrata by the addition of an internal, skeleton. When, therefore, the external and internal skeletons make their appearance, it is to afford the muscular system additional surface and leverage, and to enable it to act with greater precision in a given direction. The skeleton, since it cannot move of itself, is consequently to be regarded as an adjunct or auxiliary of the muscular

system. As the muscles are accurately moulded to the bones and to each other, either directly or indirectly, by tendons, and the joints and muscles move in perfect harmony, while the bones are unyielding or rigid, it follows that the osseous system acts as a break or boundary to the muscular one, and hence the arbitrary division of muscles into extensors and flexors, pronators and supinators, abductors and adductors. Instead, however, of dividing the muscles into sets, it would be more intelligible, and, I believe, more philosophical to regard them (as has been done in the text) as forming muscular circles or cycles interrupted by bones, whose articular surfaces transmit the motions generated in the muscular cycles in the desired direction. If this plan be adopted, the voluntary system of muscles is readily assimilated to the involuntary, and both are referred to their original, the *continuous elementary fibre*. This view is favoured by analogy, and by the fact that the muscular system in the higher vertebrates is in a state of tonicity, that is, equally balanced or oscillating between two imaginary fixed points, and ready to act, through its extensors and flexors, abductors and adductors, pronators and supinators, with surprising rapidity; the contraction of the extensors on all occasions involving the relaxation of the flexors, and so of the others. The most highly organised animal may, in this sense, be regarded as a living mass whose parts (hard, soft, and otherwise) are accurately adapted to each other; every part reciprocating with scrupulous exactitude, and rendering it difficult to determine where motion begins and where it terminates.

There are in animals very few simple movements, that is, movements occurring in one plane and produced by the action of two muscles. Locomotion is for the most part produced by the consentaneous action of a great number of muscles; these or their fibres pursuing a variety of directions. This is particularly true of the movements of the extremities in walking, swimming, and flying.

Muscles are divided into the voluntary, the involuntary, and the mixed, according as the will of the animal can wholly, partly, or in no way control their movements. The voluntary muscles are principally concerned in the locomotion of animals, and are, for the most part, spirally arranged. They provide the power which moves the several orders of levers into which the skeleton of an animal resolves itself.

The movements of the voluntary and involuntary muscles are essentially wave-like in character, that is, they spread from certain centres, according to a fixed order, and in given directions. In the extremities of animals the centripetal or converging muscular wave on one side of the bone to be moved, is accompanied by a corresponding centrifugal or diverging wave on the other side; the bone or bones by this arrangement being perfectly under control, and moved to a hair's-breadth. The centripetal or converging, and the centrifugal or diverging waves of force are, as already indicated, correlated.[1] Similar remarks may be made regarding the different parts of the body of the serpent when creeping, of the body of the fish when swimming, of the wing of the bird when flying, and of our own extremities when walking. In all those cases the moving parts are thrown into curves or waves definitely correlated.

It may be broadly stated, that in every case locomotion is the result of the opening and closing of opposite sides of muscular cycles. By the closing or shortening, say of the flexor halves of the cycles, and the opening or elongation of the extensor halves, the angles formed by the osseous levers with each other are diminished and the limb or parts of it are elongated; by the closing or shortening of the extensor halves of the cycles, and the opening or elongation of the flexor halves, the angles formed by the osseous levers are increased, and an opposite result produced; this is seen to advantage in the movements of lazy tongs as shown at Fig. 345, A, B. The alternate diminution and increase of the angles formed by the osseous levers produce the movements of walking, swimming, and flying. The muscular cycles of the trunk and extremities are so disposed with regard to the bones or osseous levers, that they in every case produce a maximum result with a minimum of power. The origins and insertions of the muscles, the direction of the muscles and the distribution of the muscular fibres insure, that if power is lost in moving a lever, speed is gained, there being an apparent but never a real loss. The variety and extent of movement are secured by the obliquity of the muscular fibres to their tendons; by the obliquity of the tendons to the bones they are to move; and by the proximity of the attachment of the muscles to the several joints. As muscles are capable of shortening and elongating nearly a fourth of their length, they readily produce the precise kind and degree of motion required in any particular case.[2]

The force of muscles, according to the experiments of Schwann, increases with their length. It is a curious circumstance, and worthy the attention of those interested in homologies, that the voluntary muscles of the superior and inferior extremities, and more especially of the trunk, are arranged in longitudinal, slightly oblique, oblique, and, more or less, transverse spiral lines, and in layers or strata precisely as in the ventricles of the heart and

[1] Muscles virtually possess a pulling and pushing power; the pushing power being feeble and obscured by the flaccidity of the muscular mass. In order to push effectually, the pushing substance must be more or less rigid.

[2] The extensor muscles preponderate in mass and weight over the flexors, but this is readily accounted for by the fact, that the extensors, when limbs are to be straightened, always work at a mechanical disadvantage. This is owing to the shape of the bones, the conformation of the joints, and the position occupied by the extensors.

hollow muscles generally.[1] If, consequently, I eliminate the element of bone from these several regions, I reproduce a typical hollow muscle ; and what is still more remarkable, if I compare the bones removed (say the bones of the anterior extremity of a quadruped or bird) with the cast obtained from the cavity of a hollow muscle (say the left ventricle of the heart of the mammal), I find that the bones and the cast are twisted upon themselves, and form elegant screws, the threads or ridges of which run in the same direction (Fig. 305, A, B, C, p. 1079). This affords a proof that the involuntary hollow muscles supply the type or pattern on which the voluntary muscles are formed.

It has been the almost invariable custom in teaching anatomy, and such parts of physiology as pertain to animal movements, to place much emphasis upon the configuration of the bony skeleton as a whole, and the conformation of its several articular surfaces in particular. This is very natural, as the osseous system stands the wear and tear of time, while all around it is in a great measure perishable. It is the link which binds extinct forms to living ones, and we naturally venerate and love what is enduring. It is no marvel that Oken, Goethe, Owen, and others should have attempted such splendid generalisations with regard to the osseous system—should have proved with such cogency of argument that the head consists of a series of expanded vertebræ. The bony skeleton is a miracle of design very wonderful and very beautiful in its way. But when all has been said, the fact remains that the skeleton, when it exists, forms only an adjunct of locomotion and motion generally. All the really essential movements of an animal occur in its soft parts. The osseous system is therefore to be regarded as secondary in importance to the muscular, of which it may be considered an extension and differentiation. Instead of regarding the muscles as adapted to the bones, the bones ought to be regarded as adapted to the muscles. Bones have no power either of originating or perpetuating motion. This begins and terminates in the muscles. Nor must it be overlooked, that bone makes its appearance comparatively late in the scale of being ; that innumerable creatures exist in which no trace either of an external or internal skeleton is to be found ; that these creatures move freely about, digest, circulate their nutritious juices, and blood when present, multiply, and perform all the functions incident to life. While the skeleton is to be found in only a certain proportion of the animals existing on our globe, the soft parts are to be met with in all ; and this appears to me an all-sufficient reason for attaching great importance to the movements of soft parts, such as protoplasm, jelly masses, involuntary and voluntary muscles, &c.[2] As the muscles of vertebrates are accurately applied to each other, and to the bones, while the bones are rigid, unyielding, and incapable of motion, it follows that the osseous system acts as a boundary or limit to the muscular one. The most highly organised animal is, strictly speaking, to be regarded as a living mass whose parts (hard, soft, and otherwise) are accurately adapted to each other, every part reciprocating with scrupulous exactitude, and rendering it difficult to determine where motion begins and where it terminates.

§ 339. The Distribution of the Muscles of the Horse.

Fig. 347 shows the more superficial of the muscular masses which move the bones or osseous levers of the horse, as seen in the walk, trot, gallop, &c. A careful examination of these carneous masses makes it clear that they run longitudinally, transversely, and obliquely ; the longitudinal and transverse muscles crossing each other at nearly right angles, the oblique ones tending to cross at various angles, as in the letter X. The crossing is seen to most advantage in the deep muscles.

In order to understand the twisting which occurs to a greater or less extent in the bodies and extremities (when present) of all vertebrated animals, it is necessary to reduce the bony and muscular systems to their simplest expression. If motion be desired in a dorsal, ventral, or lateral direction only, a dorsal and ventral or a right and left lateral set of longitudinal muscles acting upon straight bones articulated by an ordinary joint will suffice. In this case the dorsal, ventral, and right and left lateral muscles form *muscular cycles ;* contraction or shortening on the one aspect of the cycle being accompanied by relaxation or elongation on the other, the bones and joints forming as it were the diameters of the cycles, and oscillating in a backward, forward, or lateral direction in proportion to the degree and direction of the muscular movements. Here the motion is confined to two planes intersecting each other at right angles. When, however, the muscular system becomes more highly differentiated, both as regards the number of the muscles employed, and the variety of the directions pursued by them, the bones and joints also become more complicated. Under these circumstances, the bones, as a rule, are twisted upon them-

[1] "On the Arrangement of the Muscular Fibres in the Ventricles of the Vertebrate Heart, with Physiological Remarks," by the Author. (*Philosophical Transactions*, 1864)

"On the Muscular Arrangements of the Bladder and Prostate," by the Author. (*Philosophical Transactions*, part i., 1867.)

"On the Distribution of the Fibres of the Muscular Tunics of the Stomach in Man and other Mammalia," by the Author. (*Proceedings of the Royal Society*, June 20, 1867, vol. xvi.)

[2] Lectures "On the Physiology of the Circulation in Plants, in the Lower Animals, and in Man." by the Author, (*Edinburgh Medical Journal* for September 1872.)

selves, and their articular surfaces present various degrees of spirality to meet the requirements of the muscular system. Between the straight longitudinal muscles, therefore, arranged in dorsal and ventral, and right and left lateral sets, and those which run in an oblique and more or less transverse spiral direction, and between the simple hinge joint whose motion is confined to one plane and the ball-and-socket joints whose movements are universal, every degree of obliquity and spirality is found in the direction of the muscles, and every possible modification in the disposition of the articular surfaces. In the fish the muscles are for the most part arranged in dorsal, ventral, and lateral sets, which run longitudinally and obliquely ; and, as a result, the movements of the trunk, particularly towards the tail, are from side to side and sinuous. As, however, oblique fibres are also present, and the tendons of the longitudinal muscles in some instances cross obliquely towards the tail, the fish has also the power of twisting its trunk (particularly the lower half) as well as the caudal fin. In a mackerel which I dissected, the oblique muscles were represented by the four lateral masses occurring between the dorsal, ventral, and lateral longitudinal muscles—two of these being found on either side of the fish, and corresponding to the myocommas or "*grand muscle*

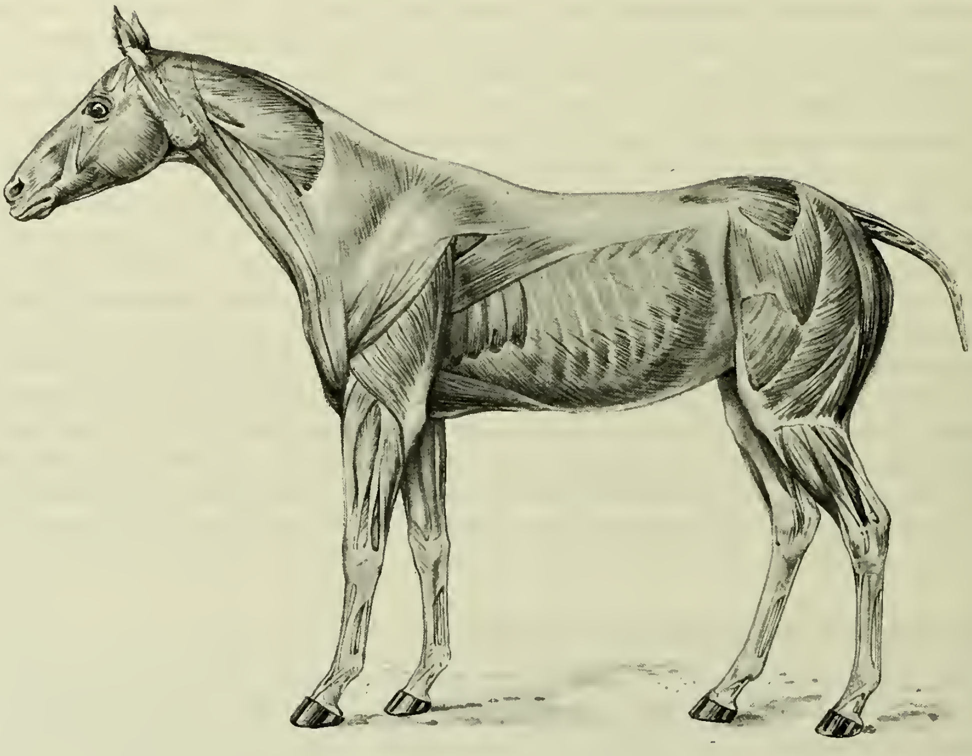


Fig. 347.—The superficial muscles of the horse. Shows the plicated spiral arrangements of the muscles at the shoulders and hips: also the nearly straight muscles of the limbs, and the oblique and transverse muscles of the head, neck, and body. The plicated arrangements of the muscles at the shoulders and hips are the best possible for communicating to the anterior and posterior extremities the rotatory, circumductory, curved, figure-of-8 movements which characterise them. The shoulder muscles are so disposed that they make rotatory, circumductory, curved, figure-of-8 movements of the fore-limbs a necessity. The same is true of the hip muscles, and those of the posterior extremities (after Lupton : the movements analysed and described by the Author).

latéral" of Cuvier. The muscular system of the fish would therefore seem to be arranged on a fourfold plan, there being four sets of longitudinal muscles, and a corresponding number of slightly oblique and oblique muscles, the oblique muscles being spiral in their nature, and tending to cross or intersect at various angles, an arrest of the intersection, as it appears to me, giving rise to the myocommas and to that concentric arrangement of their constituent parts so evident on transverse section. This tendency of the muscular fibres to cross each other at various degrees of obliquity may also be traced in several parts of the human body, as, for instance, in the deltoid muscle of the arm and the deep muscles of the leg. Numerous other examples of penniform muscles might be adduced. Although the fibres of the myocommas have a more or less longitudinal direction, the myocommas themselves pursue an oblique spiral course from before backwards and from within outwards, that is, from the spine towards the periphery, where they receive slightly oblique fibres from the longitudinal dorsal, ventral, and lateral muscles. As the spiral oblique myocommas and the oblique fibres from the longitudinal muscles act directly and indirectly upon the spines of the vertebræ, and the vertebræ themselves to which they are specially adapted, and as both sets of oblique fibres are geared by interdigitations to the fourfold set of longitudinal muscles, the lateral,

sinuous, and rotatory movements of the body and tail of the fish are readily accounted for. The spinal column of the fish facilitates the lateral sinuous twisting movements of the tail and trunk, from the fact that the vertebræ composing it are united to each other by a series of modified universal joints—the vertebræ supplying the cup-shaped depressions or sockets, the intervertebral substances, the prominences or balls.

The same may be said of the general arrangement of the muscles in the trunk and tail of the cetacea; the principal muscles in this case being distributed, not on the sides, but on the dorsal and ventral aspects. The lashing of the tail in the whales is consequently from above downwards or vertically, instead of from side to side or laterally. The spinal column is jointed as in the fish, with this difference, that the vertebræ (especially towards the tail) form the rounded prominences or balls, the miniscus or cup-shaped intervertebral plates the receptacles or sockets.

When limbs are present, the spine may be regarded as being ideally divided, the spiral movements, under these circumstances, being thrown upon the extremities by typical ball-and-socket joints occurring at the shoulders and pelvis. This is peculiarly the case in the seal, where the spirally sinuous movements of the spine are transferred directly to the posterior extremities.[1] The development of the frog is highly instructive in this connection (Figs. 348 and 349).

Fig. 348.

Fig. 349.

Fig. 348.—Tadpole developing legs but still retaining the swimming tail.

Fig. 349.—Fully developed adult frog with four well formed legs and no tail (after Dalton: the development described by the Author).

In the tadpole stage there is a rudimentary spinal column and a fish-like swimming tail. As development proceeds four legs gradually appear, the swimming tail simultaneously disappearing. In the adult frog there is a

Fig. 350.—A. Siren (*Siren lacertina*). B. Amphiuma (*Amphiuma tridactylum*). C. Menobranchus (*Menobranchus lateralis*) (after Cuvier).

well-developed spinal column with four legs; the spinal column and the legs having their appropriate muscles. The legs and concomitant muscles may very properly be regarded as outgrowths of the trunk of which the back bone is the central system. The frog swims and walks by alternately flexing and extending its fore and hind legs; the

[1] That the movements of the extremities primarily emanate from the spine is rendered probable by the remarkable powers possessed by serpents. "It is true," writes Professor Owen (p. 261), "that the serpent has no limbs, yet it can outclimb the monkey, outswim the fish, outleap the jerboa, and, suddenly loosing the close coils of its crouching spiral, it can spring into the air and seize the bird upon the wing." . . . "The serpent has neither hands nor talons, yet it can outwrestle the athlete, and crush the tiger in the embrace of its ponderous overlapping folds." The peculiar endowments which accompany the possession of extremities, it appears to me, present themselves in an undeveloped or latent form in the trunk of the reptile.

two fore legs and the two hind legs acting in pairs and together as in ourselves in swimming. The toad, however (a nearly allied animal), crawls by the diagonal movements of its fore and hind limbs, and in so doing develops the double sinuous figure-of-8 curves seen in the creeping of the serpent and the swimming of the fish, and also in the walking and running of the biped and quadruped.

The rule is that if the body be eel-like, as in certain lizards, or if a powerful swimming tail be retained or

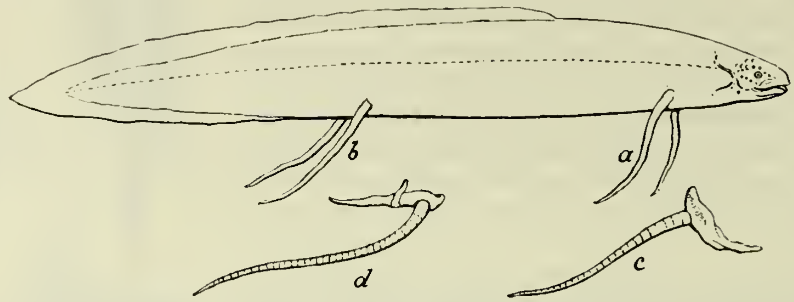


FIG. 351.—*Protopterus annectens*, Günther. (*Lepidosiren annectens*, Owen.) *a*, Filamentary anterior extremities or pectoral fins; *b*, filamentary posterior extremities or ventral fins; *c*, scapulo-coracoid bone with jointed cartilaginous ray of pectoral fin; *d*, pelvic cartilage with jointed cartilaginous ray of ventral fin (after Owen).

developed, the limbs are rudimentary and small. This is especially the case in the siren, amphiuma, and menobranchus (Fig. 350).

A good example of the powerful swimming tail, fish shape, and rudimentary limbs is seen in the Lepidosiren of Owen (Fig. 351).

Other examples occur in the water newt and the crocodile, where the great swimming tail quite dwarfs the limbs (Fig. 352).

Extreme examples of the suppression, subordination, and modification of limbs in connection with swimming tails are seen in the sea mammals, especially the whales, dolphins, dugongs, and manatees, where the limbs have virtually disappeared in favour of large, finely-modelled, effective swimming tails. Similar remarks are to be made of the seals, and walruses, where the limbs are small and the feet, especially the posterior ones, large and webbed; the posterior limbs and large webbed feet being applied to the water by a sculling motion after the manner of the fish tail.

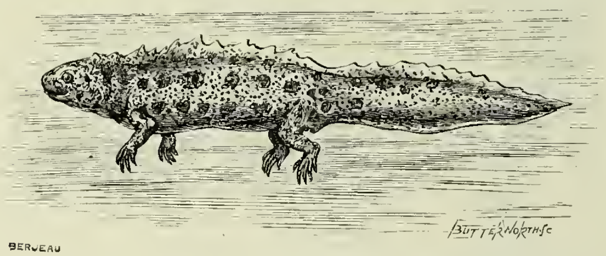


FIG. 352.—The crested newt (*Triton cristatus*) (after Dallas).

§ 340. The Travelling Surfaces of Animals Modified and Adapted to the Medium on or in which they Move.

These various modifications as between swimming tails and limbs afford so many examples of design; the swimming organ having a certain shape, and acting in a particular way, according to fixed laws, which may not be departed from. As already explained, the travelling organs, and the size, shape, and movements thereof, must in every instance be adapted to the media on or in which the animals are to live and move. Animals are in every case conditioned, that is, adapted to their environment.

While the fishes and sea mammals (whales, dolphins, dugongs, and manatees) are admirably adapted for swimming, they are absolutely helpless on land; the seals, sea-lions, and walruses, so graceful on the water, hobble about in the most ridiculous manner on shore. Similarly, land animals, strictly speaking, make a sorry figure in the water. They, moreover, can only remain in this medium for comparatively short intervals. Conversely, water and land animals (fishes and quadrupeds), unless specially modified, make unsuccessful and very awkward attempts at flight. The travelling organs and movements of animals are adapted to the fulcra formed by the earth, water, and air respectively. The various fulcra demand specially constructed levers which, of necessity, take the form of feet, fins, flippers, and wings. There is no getting away from the mechanics of locomotion; the physical conditions must in every instance be scrupulously and adequately met.

The limbless condition of animals obtains both in the water and on the land. The whale and dolphin supply

examples of the former ; the serpent and certain lizards of the latter. Those who believe that all the land animals originally came out of the sea will readily agree with me in thinking that the spinal column must be regarded as the parent of the limbs, not only in their most rudimentary, but also in their most highly developed forms.

Limbs, when present, are provided with their own muscular cycles of extensor and flexor, abductor and adductor, pronator and supinator muscles—these running longitudinally and at various degrees of obliquity, and enveloping the hard parts according to their direction—the bones being twisted upon themselves and furnished with articular surfaces which reflect the movements of the muscular cycles, whether these occur in straight lines anteriorly, posteriorly, or laterally, or in oblique lines in intermediate situations. The straight and spiral oblique muscles are principally brought into play in the movements of the extremities of quadrupeds, bipeds, &c., in walking ; in the movements of the tails and fins of fishes, whales, &c., in swimming ; and in the movements of the wings of insects, bats, and birds in flying. The straight and spiral oblique muscles are usually associated, and co-operate in producing the movements in question ; the amount of rotation in a part always increasing as the spiral oblique muscles preponderate. The combination of ball-and-socket and spiral hinge-joints, with their concomitant spiral, oblique, and longitudinal muscular cycles (the former occurring in their most perfect forms where the extremities are united to the trunk, the latter in the extremities themselves), enable the animal to present, when necessary, an extensive resisting surface the one instant, and a greatly diminished and a comparatively non-resisting one the next. This arrangement secures the subtlety and nicety of motion demanded by the several media at different stages of progression.

The feet of land animals, because of the hard, unyielding nature of the earth, are small. In those land animals which take to the water occasionally, the feet, as a rule, are furnished with membranous expansions extending between the toes. Of such the frog, triton, crocodile, beaver, otter, ornithorhynchus, walrus, seal, sea-lion, &c., may be cited. The triton and crocodile, in addition to the membranous expansion occurring between the toes, are supplied with a powerful swimming-tail, which adds very materially to the surface engaged in natation. Those animals, one and all, walk awkwardly, it always happening that when the extremities are modified to operate upon two essentially different media (as, for instance, the land and water), the maximum of speed is attained in neither. For this reason those animals which swim the best, walk, as a rule, with the greatest difficulty, and *vice versâ*, as the movements of the auk and seal in and out of the water amply testify.

In addition to those land animals which run and swim, there are some which precipitate themselves, parachute-fashion, from very considerable heights, and others which even fly. In these the membranous expansions are greatly increased, the ribs affording the necessary support in the dragon or flying lizard, and the anterior and posterior extremities and tail in the flying lemur and bat.

Although no lizard is at present known to fly, there can be little doubt that the extinct pterodactyls (which, according to Professor Huxley, are intermediate between the lizards and crocodiles) were possessed of this power. The bat is interesting as being the only mammal at present endowed with wings sufficiently large to enable it to fly.[1] It affords an extreme example of modification for a special purpose—its attenuated body, dwarfed posterior, and greatly elongated anterior extremities, with their enormous fingers and outspreading membranes, completely unfitting it for terrestrial progression. It is instructive as showing that flight may be attained, without the aid of hollow bones and air-sacs, by purely muscular efforts, and by the flapping and opening and folding of the continuous membranes which form the wings.

As the so-called flying lizard, flying lemur, and bat connect terrestrial progression with aerial progression, so the auk, penguin, and flying-fish connect progression in the water with progression in the air. The travelling surfaces of these anomalous creatures run the movements peculiar to the three highways of nature into each other, and bridge over, as it were, the gaps which naturally exist between locomotion on the land, in the water, and in the air.

I append a plate of illustrations specially arranged to show the shapes and comparative sizes of the travelling surfaces required for the earth, water, and air respectively ; also the modifications necessary to enable the land animals to take to the water or the air, and the water and air navigating animals to take to the land.

The rule (and there is no exception) is, that the travelling organs of animals increase in size in a direct ratio to the instability of the medium traversed. Thus, small travelling surfaces (feet) suffice for land transit, the land furnishing an unyielding fulcrum ; larger travelling surfaces (feet, fins, and flippers) being required for water transit, the water supplying a yielding, though virtually incompressible fulcrum ; still larger travelling surfaces (wings) being required for aerial transit, the air providing a still more yielding but highly compressible fulcrum. The various modifications in the size and shape of the travelling organs of animals afford so many proofs of design, and of the absolute necessity for complying with the mechanics of locomotion and the laws which regulate the transference

[1] The vampire bat of the Island of Bonin, according to Dr. Buckland, can also swim ; and this authority was of opinion that the pterodactyl enjoyed similar advantages. ("Eng. Cycl.," vol. iv. p. 495).

of bodies in space generally, as seen in the physical universe. The three kinds of locomotion adapted to the land, the water, and the air are conditioned in the sense, that the size, shape, and movements of the travelling organs are predetermined and adapted to the requirements of each particular case. So inexorable are the physical requirements that every animal (whatever its position in the organic kingdom) must rigorously comply with the laws which regulate each particular kind of locomotion.

Thus, the mammal destined to live habitually in water must be fish-shaped and provided with a swimming-tail, or flippers resembling fins. If it be destined to live and journey in the air, it must be provided with wings, or parachutes resembling wings. In like manner if a fish be destined to float and propel itself in the air, even for a limited period, it must be provided with greatly expanded pectoral fins which resemble wings in shape. A certain standard as regards the size, shape, and movements of the travelling organs must be reached before locomotion on the land, the water, and the air becomes possible; and the adaptability of the travelling organs to their peculiar kind of work, in every instance, determines the degree of speed attained (Plate clii.).

PLATE CLII

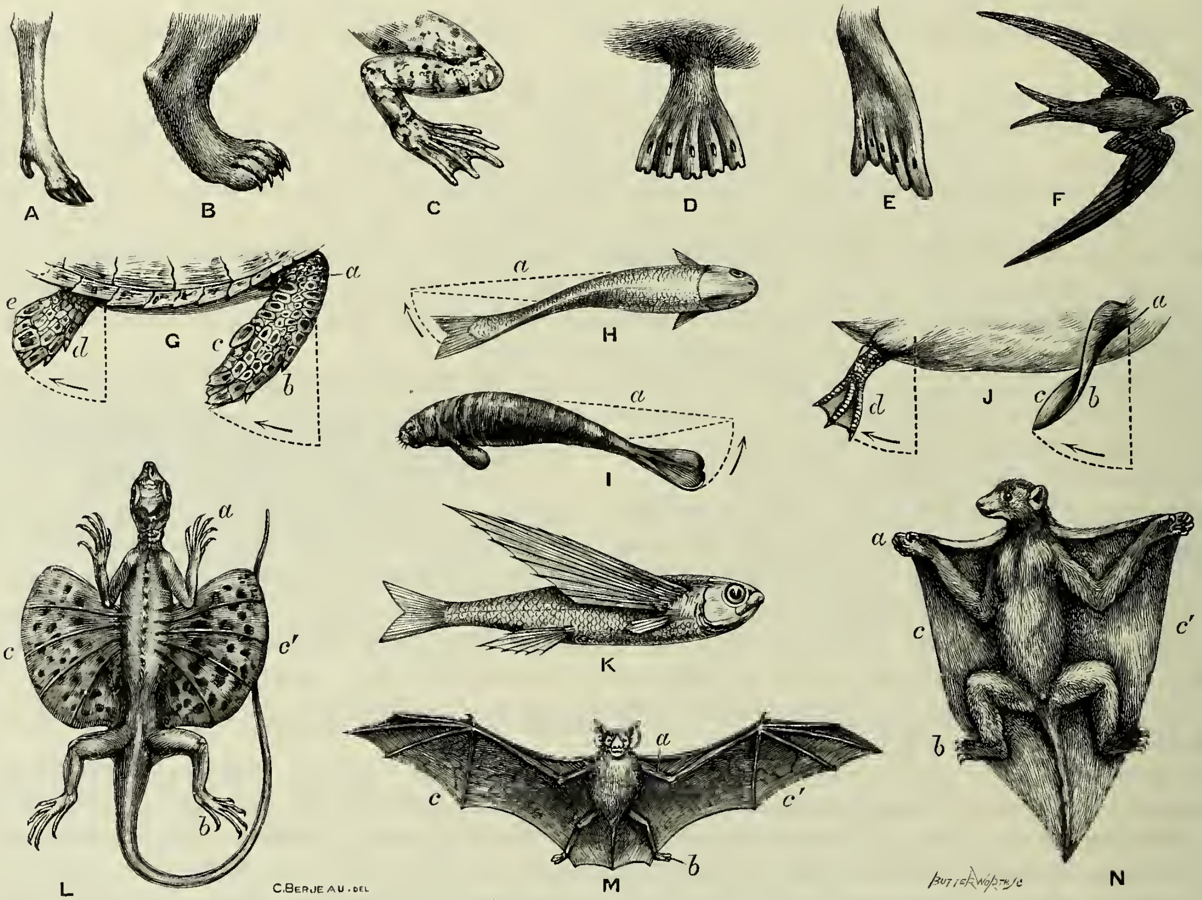


Plate clii. illustrates the remarkable disparity in the size and shape of the travelling organs of animals adapted for land, water, and air transit respectively.

From A to N inclusive, shows typical examples of travelling organs.

A. Foot of the deer. Extreme example of compressed foot for land transit. The ox and the horse furnish other examples.
B. Foot of the otter, slightly webbed. Adapted for land and water transit.
C. Foot of the frog. This foot is expanded and webbed and is best adapted for water transit (swimming).
D. Foot of the ornithorhynchus greatly expanded and webbed and mainly adapted for swimming.
E. Foot of the seal greatly modified, expanded and webbed. Used almost exclusively for swimming. The seal walks badly on land. It hobbles along by undulatory movements.
F. Swallow with anterior extremities very greatly expanded to form wings which are clothed with feathers. The travelling organs in this case when compared with the size and weight of the body are excessively large. They are specially designed to act on the air, which is the thinnest, lightest, and most unstable of the media traversed.
G. The turtle. The anterior and posterior extremities in this case are modified and considerably expanded; the expansion being largely in excess of A, B, C, D, and E, though less than in F. The anterior extremities, moreover, are true wings, in the sense that

PLATE CLII (*continued*)

they are movable, elastic structures which taper and are strongest at the root and anterior margin (*a*, *b*) and thinnest and weakest at the tip and posterior margin (*c*). The posterior extremities (*d*, *e*) are similarly modified, but more resemble feet. They are almost wholly employed in natation.

H. Fish with powerful swimming tail. In the fish nearly half of the body is engaged in natation. The tail is applied to the water laterally or from side to side.

I. The manatee, a fish-shaped, swimming mammal having a large, finely shaped, swimming tail. In this case, the tail is applied to the water vertically, or from above downwards. The same holds true of the dugong, porpoise, whale, &c. The vertical movements of the tail enable those remarkable animals readily to reach the surface of the water for breathing purposes.

J. The penguin, a bird adapted almost exclusively for swimming and diving. It has very small, featherless, strong wings, and expanded webbed feet. The wings are elastic and taper from the root to the tip, and from the anterior (*a*, *b*) to the posterior (*c*) margin. They yaw and twist screw-fashion in action, and enable the bird to fly and dive in the water with great celerity and in any direction. The feet (*d*) can act independently of the wings, or in concert with them.

K. The flying-fish. This singular animal is provided with very large, and powerful, pectoral fins resembling wings, which enable it to leave the water and take flights of from two to three hundred yards in the air.

L. The flying lizard. In this case the anterior (*a*) and posterior (*b*) extremities and ribs support a membranous expansion (*c*, *c′*) by the aid of which it flies for considerable distances in a slightly downward curved direction. The membranous expansion is not moved to any great extent by the extremities, and acts mainly as a parachute; the parachute can, however, be controlled within limits.

M. The bat. This quaint little mammal has attained to the dignity of flight. As in the flying lemur its flying membrane (*c*, *c′*) is supported by the anterior (*a*) and posterior (*b*) limbs. The flying membrane of the bat is alternately elevated and depressed with great vigour as in all flying creatures. This alternate elevation and depression of the flying membrane distinguishes it from the parachute in the ordinary sense. A parachute mainly supports; a wing at once supports and propels (the Author, 1867).

N. The flying lemur. In this instance, the membranous expansion or parachute (*c*, *c′*) is supported by the anterior (*a*) and posterior (*b*) extremities, and tail. This strange animal can all but fly. It glides by the aid of its parachutes from the tops of lofty trees and often for long distances, but always in a slightly downward, curved direction. The anterior and posterior limbs, feet, and tail regulate the tension and angles made by the parachute which is under control.

MOVEMENTS IN RUDIMENTARY LIVING MATTER

Before entering on a final consideration of the apparatus by which locomotion is effected in the higher animals it will be necessary to say a few words regarding the movements of living matter in its rudimentary forms.

In the protoplasm of plants and animals irregular movements occur; the protoplasm assuming various and remarkable shapes. Similarly, the white corpuscles of the blood change their form; they also change locality, and migrate.

The mycetozoon (a plant discharging what are virtually animal functions) advances and withdraws its plasmodium (the protoplasmic mass forming its body) when searching for food, when feeding, and after feeding.

The amœba, one of the simplest of animals, likewise assumes a great variety of forms, and moves from place to place. Spermatozoa exhibit characteristic movements. The cells of plants and animals, in many cases, are endowed with independent movements, those of certain plants moving freely about in water until they find a suitable anchorage and habitat for growing. In such instances the cells are provided with vibratile hairs or cilia, which are endowed with independent, co-ordinated movements. Analogous in many respects to the cilia in question are the sensitive moving tentacles or hair-like processes found on the leaves of insectivorous plants such as the sundew, Venus's fly-trap, &c. There are also intercellular movements seen in *Chara*, *Vallisneria* and other plants. Then come rhythmic movements in certain plants such as *Volvox globator*, and in rudimentary animals where the vacuoles open and close with time-regulated beat. The hearts of animals also act rhythmically.

The sarcous elements of muscles, moreover, exhibit wave and rhythmic movements. The opening and closing rhythmic movements which occur at definite intervals in plants and animals are allied to the vibratile movements witnessed in vibrios, in spermatozoa, and in cilia. The opening and closing, vibratile, wave movements seen in rudimentary structures prefigure and herald in a most unmistakable manner all the movements witnessed in muscles and in the locomotion of animals as a whole. The movements in plants and animals are frequently spiral in their nature.

One has only to examine living seminal fluid under the microscope to be convinced of this. The spermatozoids are seen to propel themselves by a series of spiral undulations in every respect analogous to those made by the tadpole or young frog, a vertebrate in process of formation. The development of the frog is full of interest. In its early tadpole stages, as stated, it swims exactly as a fish does; in its later stages its swimming-tail gradually disappears and four swimming and walking legs gradually appear. The legs take the form of buds or outgrowths, and when completed assume, as far as locomotion is concerned, the function originally discharged by the rudimentary spinal column.

It will be seen that the movements exhibited by plants and the lowest animal forms occur in soft, rudimentary structures where no trace of either muscle, bone, or nerve can be discovered.

The movements are, for the most part, conditioned ; that is, they are due to a controlling and regulating power acting in a given direction and to given ends. They are, further, in not a few cases, the result of feeling and knowing in a restricted sense, and so partake of the nature of voluntary movements as observed in the higher and highest animals. The power of moving in its ultimate particles is a fundamental endowment necessary to the protection and well-being of the individual, whether plant or animal. The movements may be particular (molecular) or general (movements in the mass) or partly the one and partly the other. In every case, and this is important, the movements in living things occur in the soft parts, whether protoplasm, cells, or tissues. It is a mistake to suppose that movements can only occur in muscles provided with nerves, and that muscular movements in order to be effective must be connected with bones, or with bones and joints. As a matter of fact, all the movements which take place in plants and the lowest animal forms have no connection whatever with either nerves, muscles, or bones. In like manner muscles can act effectively without bones, as in the œsophagus, stomach, intestines, rectum, bladder, uterus, heart, &c. It is only in the higher animal forms that muscles, nerves, and bones appear, and that muscles and nerves are associated with bones for the purposes of locomotion. In every instance, and I emphasise the point, movements begin and terminate in the muscles when these are present. The bones with their joints are at best accessory structures in animal progression. The bones, moreover, are moulded and adapted to the muscles, and not the converse.

The bones engaged in locomotion are, for the most part, spiral, and the joints spiral, or universal ; that is, ball-and-socket.

The muscles, as already pointed out, are arranged in straight, spiral, oblique, and transverse lines, in two sets, and, in many cases, cross or tend to cross each other ; the muscles forming cycles which as a rule invest two bones on opposite sides with a spiral joint between. Where ball-and-socket joints occur, as at the shoulders and hips, muscular masses with the fibres running in straight, oblique, very oblique, and transverse spiral directions are found. In bones with spiral joints, the movements are mainly those of flexion and extension, pronation and supination : in those with ball-and-socket joints the movements are those of rotation, circumduction, abduction, and adduction. The spiral joints, as a rule, occur in the limbs ; the ball-and-socket joints where the limbs are united to the trunk.

As explained, the muscles and bones are complementary structures, and both are necessary to locomotion in the higher animals. The point I wish to emphasise is that the muscles and not the bones lead in all the higher animal movements. The expression, the grace, and the dignity of movement are all referable to muscular action. Dignity of deportment, in turn, implies a well-formed, normal skeleton.

The flexible spinal column is admirably adapted to display to advantage every kind of muscular movement. It forms the fundamental, the central axis, so to speak, in the locomotion of vertebrates. Its appropriate muscles can cause it to move forwards, backwards, laterally, and obliquely in almost every direction. They can, moreover, develop in it the most delicate curves, sinuosities, and spirals.

The extraordinary powers of movement residing in the spinal column are due to its physical configuration. It consists of a large number of small, short, square-shaped bones, the so-called vertebræ, and, as a rule, every two of these have placed between them an intervertebral disc or plate of highly elastic cartilage which acts as a cushion or buffer and prevents shock. The vertebræ are geared together and kept in position by ligaments of fibrous tissue, with the result that while comparatively little movement is permitted between any two vertebræ, the movements of the spinal column, as a whole, are of a most extensive and comprehensive character.[1] The spinal column in addition to its sinuous forward, backward, and lateral movements can be made to twist and untwist, and to rotate upon an imaginary axis well seen in the swimming of some fishes.

The spinal column and the muscles and other structures investing it are, in a sense, the parents of the limbs. The limbs appear as buds or outgrowths of the trunk during development, and in many adult animals such as the siren, amphiuma, the porpoise, whale, &c., they are mere rudiments. Many proofs can be adduced in support of this view. The serpent is a typical vertebrate. It has no limbs, yet it can by alternate curvature of its spinal column aided by its ribs and horny ventral plates move along the ground with great celerity. It can also swim, climb trees, and perform a great variety of complicated evolutions.

In like manner the fish is devoid of limbs, nevertheless it can by the spiral, twisting, sinuous movements of its powerful swimming-tail, in some cases outrace even swift steamships.

The spinal column of the fish is particularly deserving of attention from the fact that it can be made to move in curves from side to side in the long-bodied fishes, and from above downwards in the flat fishes. It can also be made to move spirally, most fishes adding a certain degree of obliquity to the strokes made by their swimming-tails.

[1] An analogous arrangement obtains in the extremities at the wrists and ankles, and also, though to a less extent, in the hands and feet.

Fishes, as a rule, swim by the aid of their bodies and tails, chiefly the latter. Some, however, such as the thresher shark, have large, powerful, pectoral fins which enable it to turn and tack about with great rapidity, and which, in conjunction with its huge heterocercal tail, permits it to turn over and seize its prey, which it does from the side and often from beneath; the capacious mouth being situated on the ventral aspect of the body. The

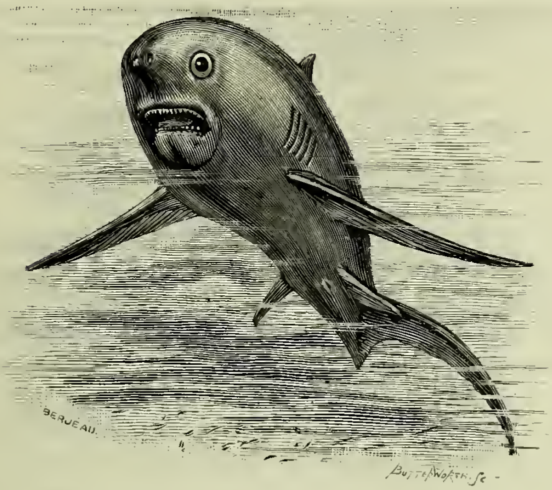


FIG. 353.

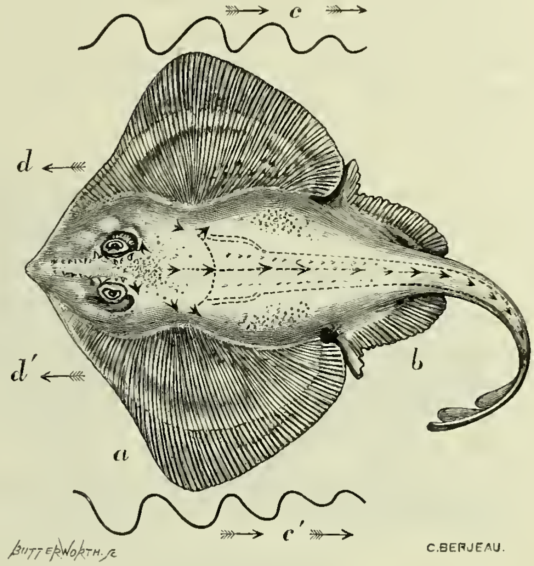


FIG. 354.

FIG. 353.—The thresher or fox shark (*Carcharias vulpes*). Shows large, powerful, swimming, pectoral fins, and huge heterocercal tail.

Taken from a photograph of an actual specimen supplied to the Author by a friend (E. M.) for the present work.

FIG. 354.—Illustrates the swimming, according to the Author, of the skate (*Raja clavata*) by what are virtually undulatory flying movements. *a*, *b*, Greatly expanded, graduated, elastic, lateral fins, resembling wings; *c*, *c′*, wave movements made by the lateral fins in a direction from above downwards and from before backwards; *d*, *d′*, the direction in which the skate swims.

(Drawn from nature by C. Berjeau, for the present work, from a specimen in the possession of the Author).

great pectoral fins are certainly powerful swimming organs. They are wings, in the sense that they are triangular in shape and finely graduated; being thick at the root and along the anterior margin, and thin at the tip and along the posterior margin. They are, moreover, highly elastic structures. The shape, structure, and elastic properties of these organs, of necessity, invest them with many of the peculiarities of genuine wings (Fig. 353).

That swimming and wing movements may be performed by fins, is abundantly proved by the locomotion of the flat fishes which fly through, rather than swim in, the water by a series of vertical, undulatory movements well seen in the locomotion of the skate.

The skate, and flat fishes generally, as I have frequently satisfied myself from actual observation, swim mainly by the undulating movements of their bodies and greatly developed lateral fins; the movements of the marginal fins being, to all intents and purposes, undulatory wing and flight movements (Fig. 354).

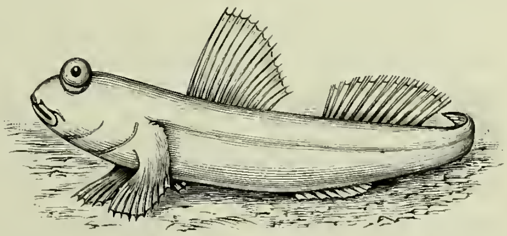


FIG. 355.—The Goby or walking fish (*Periophthalmus koelreuteri*). Shows pectoral fins used as anterior limbs for walking on the sea bottom (after Günther).

Throughout the vertebrate series there is a tendency to develop limbs, and in proportion as the limbs become more and more perfect, the functions of the spinal column disappear, and reappear in the limbs. The more perfect the limbs, and the greater the amount of work performed by them, the less the work performed by the spinal column. In the fish, the pectoral and ventral fins represent rudimentary anterior and posterior extremities. "In many blennies the ventral fins are adapted for walking on the sea-bottom. In some gobioids (*Periophthalmus*), irigloids, scorpœnioids, and pediculati, the pectoral fins are perfect organs for walking; in the gobies, *Cyclopteri* and *Discoboli*, the ventral fins act as parachutes."

Some of the mud fishes have pseudo-limbs which enable them to hobble along when they cannot swim, and one of the perches (*Anabas scandens*) similarly endowed takes to the land for short intervals, and, it is asserted, even climbs trees.[1]

[1] Daldorff. (*Transactions of the Linnean Society of London*, 1797.)

Günther, when speaking of Periophthalmus, says: "The fishes of this genus are common on the coasts of the tropical Indo-Pacific—especially on parts covered with mud, or fucus. During the ebb tide they leave the water and hunt for small crustaceans and other small animals disporting themselves on the ground which is left by the receding tide.

"With the aid of their strong pectoral and ventral fins and their tail, they hop freely over the ground, and escape danger by rapid leaps. . . . In many blennies the ventral fins have ceased to have any function, and become rudimentary, or are even entirely absent. In others the ventral fins, although reduced to cylindrical stylets, possess a distinct function, and are used as organs of locomotion by the aid of which the fish moves rapidly over the bottom."

The climbing perch (*Anabas scandens*) is said to make its way from lake to lake without difficulty and in certain cases to ascend trees. They can remain out of the water for considerable periods in virtue of a special arrangement of their gills, and are believed to feed on small animal and vegetable substances, which they find in their peregrinations.

"In 1797 Daldorff, in a memoir communicated to the Linnean Society of London, mentions that he had himself taken an Anabas in the act of ascending a palm tree which grew near a pond. The fish had reached the height of five feet above the water, and was going still higher. In the effort to do this it held on to the bark of the tree by the preopercular spikes, bent its tail, and struck in the spines of the anal fin; then released its head, and, raising it, took a new hold with the preoperculum higher up. The fish is named in the Malayan language 'the tree climber.' It rarely attains a length of seven inches." [1]

Lydekker, when writing of this phenomenal perch, remarks, "That this fish can travel long distances on land, where it drags itself along by hitching its pectoral fins round the stems of grass and other herbage, is perfectly well ascertained. With regard to its climbing power some amount of incredulity has been expressed, but it is noteworthy that its Malayan name (*undi-colli*) signifies tree-climber, while nearly a thousand years ago certain Arab travellers were informed of the existence in India of a fish that was in the habit of ascending cocoa-nut palms in order to drink their milk." [2]

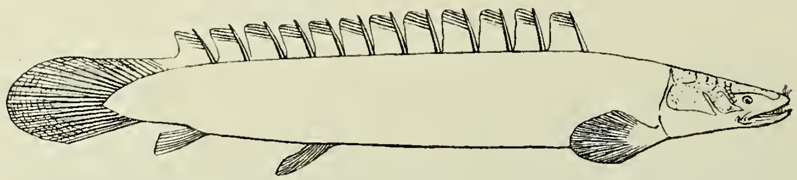


Fig. 356.—Bony pike of the Nile (*Polypterus bichir*). The fins, especially the dorsal ones, are remarkable (after Cuvier and Valenciennes).

Other anomalies occur in the mud fishes of Africa (*Protopterus annectens*) and South America (*Lepidosiren paradoxa*).

"The protopterus exhibits the simplest form of limb that is known. The pectoral and ventral fins or limbs each consist of a single ray which tapers to a point and is jointed much like a single-jointed fin-ray of an ordinary fish. These limbs are attached to arches which represent, in an imperfect condition, the corresponding pectoral and pelvic girdles of osseous fishes and amphibians" (Fig. 351, p. 1100).

"The bony pike of the Nile lives in the mud at the bottom of rivers, where it crawls or walks like a seal by means of its fins. It swims with great rapidity, much in the manner of serpents (Fig. 356). This fish presents an extraordinary appearance, from the way the dorsal fin is broken up into a succession of finlets, which vary in number in the several varieties from eight to eighteen, each formed by a spine in front and a series of rays behind. These have a striking resemblance to a wing. 'The finlets' are characterised by having their upper rays stiff like the primary feathers of a bird's wing, whilst the lower part is comparatively slack, as in the secondary and tertiary feathers of the wing." A Boulogne *chasse-marée* (fishing-boat) is rigged on the same principle, having the upper canvas of its mainmast divided up into small sails with a mainsail beneath. The dorsal finlets of the bony pike are thick at the root and anterior margin and taper and become thinner at the tip and posterior margin. They act as tiny wings in swimming, in virtue of their structure, which is essentially wing-like.

An interesting structural modification as between swimming and walking organs is met with in the so-called "swimming-crab." In this quaint creature "the last pair of legs are much flattened, the last segment being dilated into an oval plate. Several species are found in British waters; but none are such expert swimmers as the tropical species, especially those inhabiting the gulf weed of the Atlantic. The peculiar motion of the oar-like feet has given rise to the name of 'fiddler crab' often applied to them."

The development or suppression of the limbs seems to depend largely on the conditions of life and the habit of the animal. Thus animals living in water must be fish-shaped and provided with a swimming-tail or structures

[1] "The Study of Fishes," by Albert C. L. S. Günther, M.A., M.D., F.R.S., 1880, p. 487, *et seq.*
[2] "The Royal Natural History," edited by R. Lydekker, 1895.

representing it, and they must employ their spinal column and tail as their chief organs of propulsion. The limbs must be modified or even suppressed.

It is a curious circumstance that the sea mammals, such as the dugong, manatee, porpoise, and whale have rudimentary fore limbs (flippers), but no hind limbs, or the veriest traces of them. In the whale, very rudimentary hind limbs are found deeply buried in the flesh near the broadly-expanded tail. All these animals are fish-shaped.

The seal, sea-lion, and walrus also conform to the general fish-type, and trust largely to the curves formed by their spinal column and modified limbs in swimming. The seal, sea-lion, and walrus have specially constructed extremities expanded and webbed after the manner of fish tails, and as the posterior ones are arranged in the same

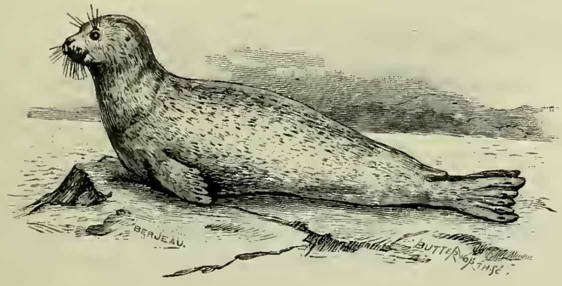


Fig. 357.

Fig. 359.

Fig. 358.

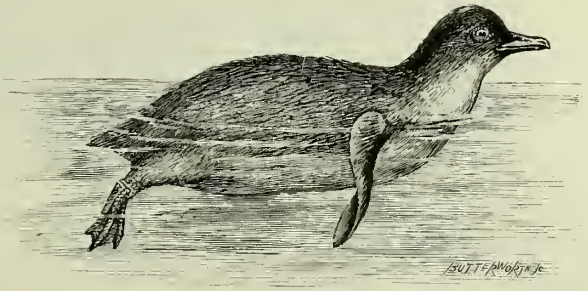


Fig. 360.

Fig. 357.—The seal (*Phoca fœtida*), likewise a mammal. Shows general fish-shape. The anterior and posterior extremities are both present and webbed. They can be expanded or closed at pleasure in swimming, and act after the manner of a fish tail (the Author, 1867).

Fig. 358.—The sea-bear, a mammal closely related to the sea-lion. In this animal, the anterior and posterior extremities, which are webbed, are larger than in the seal, especially the former. The anterior extremities enable the animal literally to fly through the water. The posterior extremities are also well developed and webbed, and are applied to the water like a fish tail in swimming, or at right angles to slow or stop forward progress (the Author, 1867).

Fig. 359.—A young specimen of the walrus (*Trichecus rosmarus*), another example of the swimming mammal. The form is less fish-shaped than in the seal, sea-bear, and sea-lion. The anterior and posterior extremities are well developed, webbed, and very useful as swimming organs (after Wood).

Fig. 360.—The little penguin (*Aptenodytes minor*). The wings of this quaint bird twist and untwist and have a screw action in swimming and diving (the Author, 1867).

plane with the body in swimming, they are applied to the water in exactly the same way that fish tails are (Figs. 357, 358, and 359).

The porpoise, whale, dugong, manatee, seal, and walrus make very considerable use of their anterior extremities (flippers), not so much in swimming as in turning and changing positions. The sea-lion is an exception. This remarkable animal makes much greater use of its anterior extremities than its posterior ones in swimming. The anterior extremities or flippers of the sea-lion are greatly developed, and as they have thick anterior and thin posterior margins, and are finely graduated, flexible and slightly twisted structures, they form true wings and are employed as such in swimming. The sea-lion literally flies in the water. In this respect it resembles the penguin, which is provided with short, rudimentary, twisted, featherless wings greatly resembling flippers (Fig. 360).

The sea-lion and penguin fly through the water at a very high speed and in the most graceful manner. It has

been my good fortune to be able to study the swimming of the manatee, porpoise, seal, walrus, sea-lion, and penguin under natural conditions.

That the vertebral column and the muscles of the trunk play an important part in animal locomotion is proved by an examination of the siren, Amphiuma, Menobranchus, and newt, figures of which have been given. In the

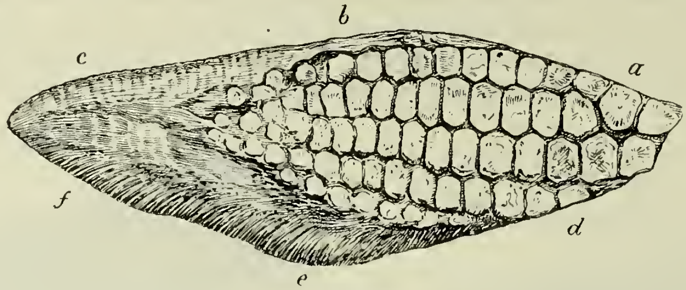


Fig. 361.—Bones and portion of the soft parts of the hind flipper of the Ichthyosaurus. *a, b, c,* Anterior thick margin; *d, e, f,* posterior thin margin (after Owen).

siren there is the eel-like body with a pair of very rudimentary anterior limbs near the head. In the Amphiuma, the body is still more elongated, with a pair of very rudimentary anterior limbs near the head and a similar pair of posterior limbs near the tail. The legs are of no use as swimming organs; the flexible body and tail performing this function. In the Menobranchus the anterior and posterior extremities are more developed. In the newt,

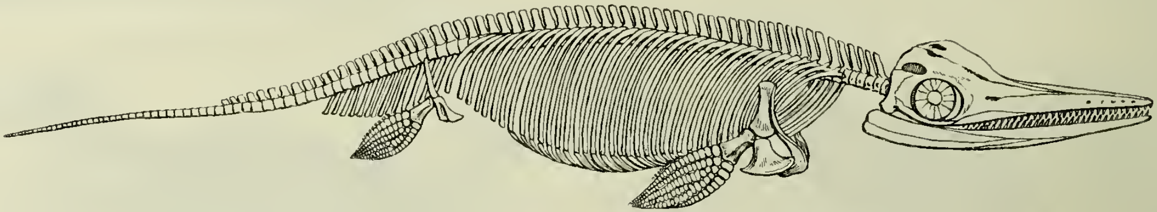


Fig. 362.—Skeleton of the Ichthyosaurus (after Cuvier).

the anterior and posterior extremities are well developed, but in this case and in the Menobranchus, natation is mainly performed by the large powerful swimming-tail. Similar remarks may be made of the crocodile family.

In the extinct Ichthyosaurus (*Ichthyosaurus communis*) the flexible vertebral column with its powerful longitudinal and spiral muscles occupies the first place as the organ of propulsion. The Ichthyosaurus, as its name

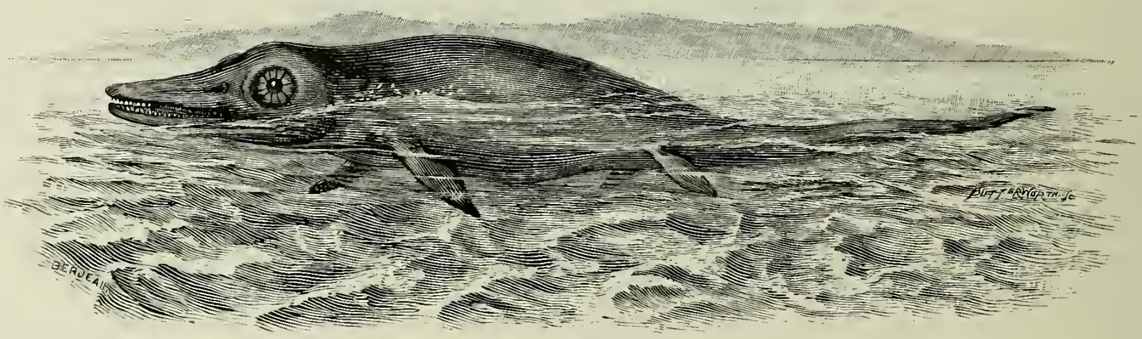


Fig. 363.—The Ichthyosaurus as restored by the Author, assisted by C. Berjeau, for the present work.

implies, was a fish-shaped saurian. It had a large, powerful swimming-tail and two pairs of well-developed flippers (anterior and posterior). The flippers and tail could act separately or in concert. The flippers, considering their great size, shape, and position, would certainly act as powerful propellers, nevertheless the monster chiefly depended for progression on its formidable swimming-tail.

I give a restoration of this interesting extinct voracious animal, taking the skeleton as my guide, and am largely indebted to the facile pencil of Mr. C. Berjeau for the spirited reproduction. I also give a representation of a flipper described and figured by Owen [1] (Figs. 361, 362, and 363).

[1] *Transactions of the Geological Society.* Second series, vol. vi., Plate xx.

The Plesiosaurus, another extinct saurian, differed greatly from the Ichthyosaurus in general appearance. It was essentially bird-like in shape, and had a very long, elegant neck and head somewhat resembling the head and

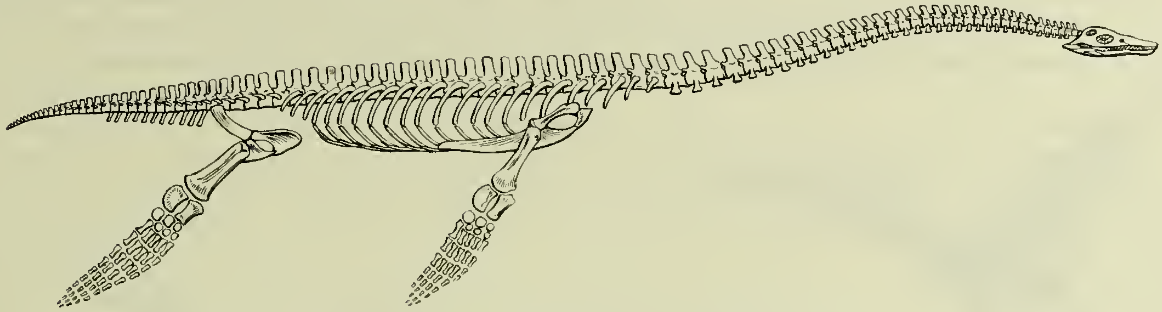


Fig. 364.—Skeleton of the Plesiosaurus (after Cuvier).

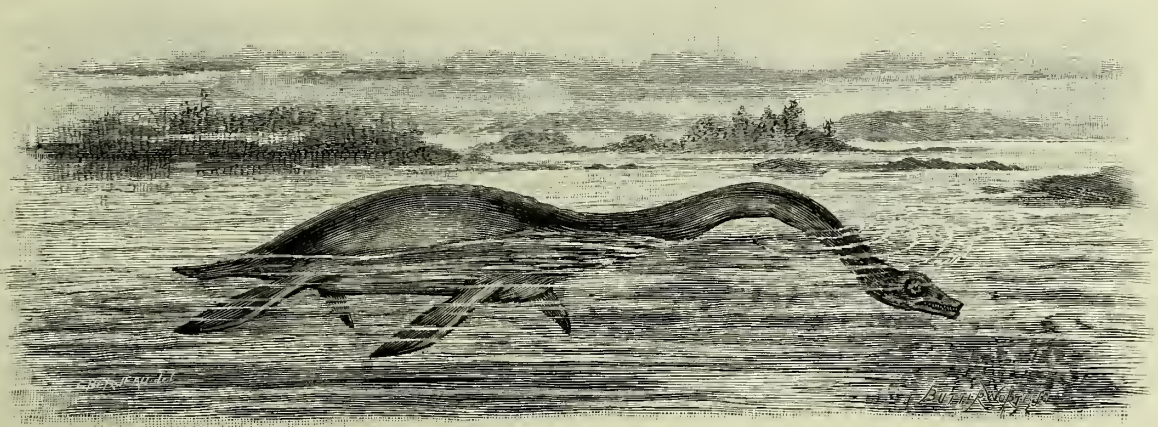


Fig. 365.—The Plesiosaurus swimming, as restored by the Author and C. Berjeau for the present work.

neck of a swan. It had no swimming-tail. On the contrary, it was provided with two pairs of long, powerful, finely-formed flippers (two anterior and two posterior). As the four flippers were carefully graduated structures (thick

Fig. 366.—The Plesiosaurus on land, as restored by the Author and C. Berjeau for the present work.

at the root and anterior margins and thin at the tip and posterior margins) and bore a general resemblance to the flippers of the sea-lion and penguin, and to wings generally, there can be no doubt that this remarkable antediluvian flew through the water at a comparatively very high speed. The four flippers of the Plesiosaurus may not inaptly

be compared to the four wings of the dragon-fly; the dragon-fly being the swiftest of all the insects. The Plesiosaurus, as far as locomotion is concerned, formed a link between the reptiles and the birds.

I have, as in the case of the Ichthyosaurus, ventured on a restoration of this very interesting extinct animal, taking the skeleton as the outline of my figure. I have again to acknowledge my indebtedness to Mr. C. Berjeau for the able assistance he has given and for the refined and vigorous effects (Figs. 364, 365, and 366).

Fig. 367.—*Pterodactylus spectabilis.* (Restored by the Author and C. Berjeau.)

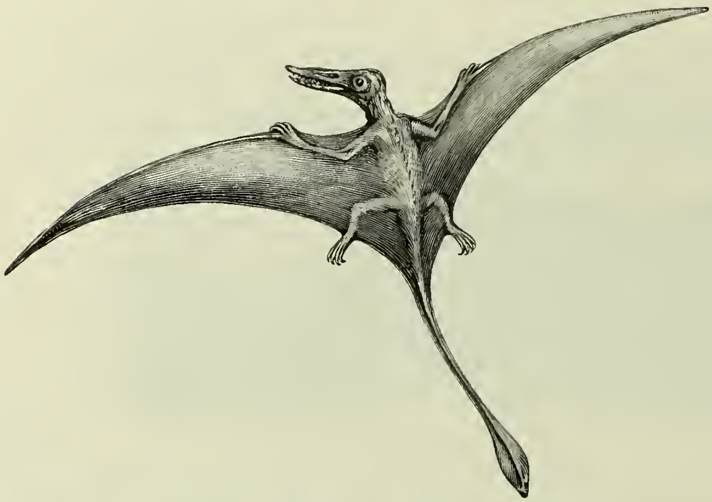


Fig. 368.—*Rhamphorhynchus muensteri* (after Marsh).

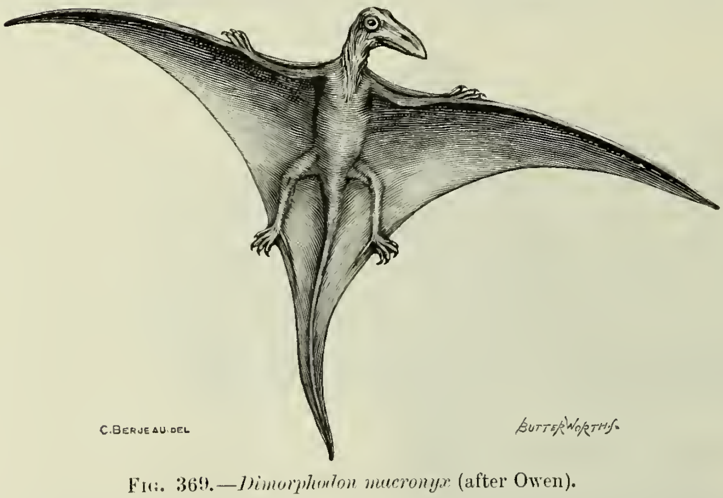


Fig. 369.—*Dimorphodon macronyx* (after Owen).

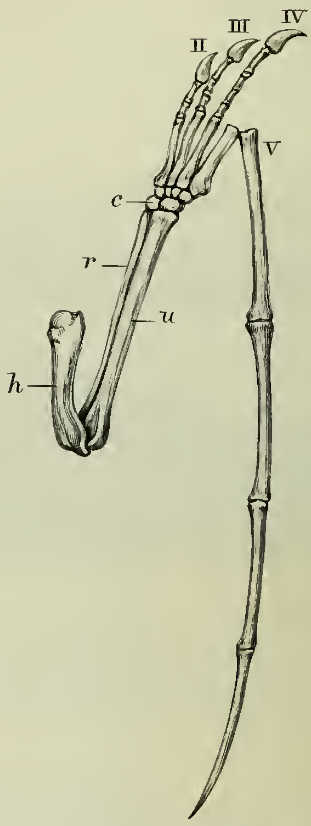


Fig. 370.—Right pectoral limb of *Scaphognathus crassirostris.* *h*, Humerus; *r*, radius; *u*, ulna; *c*, carpus; II, III, IV, V, digits—the latter (V) developed out of all proportion to the others (after Nicholson).

The flying saurians form, in some respects, a unique group. Reptilian as to character, they exhibit the general configuration of bats (mammals). They differ from bats mainly in the greater length of their vertebral columns. The flying saurians had very ample and beautifully shaped wings, and must have been exceedingly powerful and elegant flyers. They have been classified as under:—

(*a*) *Pterodactylus spectabilis.*
(*b*) *Rhamphorhynchus muensteri.*
(*c*) *Dimorphodon macronyx*.[1]

[1] Nicholson and Lydekker's "Paleontology," vol. ii.

The thick anterior margin of the wing in *Scaphognathus crassirostris* is formed by a very greatly developed fifth digit (Fig. 370).

In the bats the second digit plays the same rôle. It would be easy to multiply examples where the vertebral column preponderates over the limbs, as in the lizards, and all those animals with small, rudimentary legs, but enough has been said to show that the back bone, and its concomitant muscles, play a very important part in the locomotion of both the lower and higher animal forms.

It is one thing to know and describe animal movements ; it is, in some respects, a more difficult task to portray them correctly. This can only be done by the assistance of instantaneous photography. A knowledge of photographic methods and results becomes imperative in all modern attempts at explaining the involved and complicated subject of animal mechanics. I, consequently, devote a short section to what is practically a new and important means of research.

§ 341. Instantaneous Photography a Valuable Aid in Determining Animal Movements.

It is impossible to over-estimate the value of instantaneous photography in recording animal movements. It has quite superseded every form of registering apparatus. The latter, consisting as it does of a multiplicity of tambours, levers, styles, &c., and of cylinders and plane surfaces travelling at given speeds by the aid of clockwork, is apt to get out of order. It is, therefore, unreliable, and not unfrequently originates and perpetuates errors. This instantaneous photography never does. It, in every instance, supplies reliable information directly and at first hand.

In order to ensure accuracy, and to avoid long descriptions, I propose, whenever practicable, to employ it to illustrate what I have to say regarding walking, swimming, flying, for the following among other reasons :—

(*a*) Instantaneous photographs give accurate representations of the organs of locomotion in all possible positions.

(*b*) They give striking illustrations of the size and shape of the travelling organs when in action.

(*c*) They enable the observer to compare the moving parts of animals with fixed objects occupying vertical, horizontal, and other positions.

(*d*) They permit the operator to determine not only the time required to perform certain movements, but also to map out the areas within which the movements occur.

(*e*) They record accurately the movements of the organs of locomotion, and, what is scarcely less important, of the whole animal.

(*f*) They reveal movements which the unaided eye cannot see.

The time required to take an instantaneous photograph is so infinitesimally short (the one five-thousandth part of a second or less) that the most rapidly moving object is practically arrested in its course and as perfect an image taken of it as if it were at rest.

If a fly-wheel in rapid motion be taken with a sufficiently short exposure, the spokes of the wheel, and all the details of the spokes, stand out in bold relief. When the natural eye looks at a rapidly revolving fly-wheel, the observer sees no spokes but only a blur or indistinct image.

The same thing happens when he looks at the rapidly moving wings of an insect. Practically the most rapid animal movements can be arrested and analysed by short exposures of the camera, and the moving parts depicted in every conceivable position as if at rest. The ever varying shapes assumed by the moving parts are likewise accurately represented.

The difference between the camera with its quick-working lenses and highly sensitive plates and the natural eye consists in this : the camera receives and records an image instantaneously, or very nearly so, whereas the eye requires a considerable time to receive an impression, and the impression, when once made, remains on the retina or sensitive part of the eye for a considerable time after the object which caused it has passed away.

It follows that if a rapidly moving object be presented to the eye, and the time allowed for receiving and dismissing the impression be insufficient, a series of indistinct pictures are superposed on the retina, and a haze or blur produced. A certain amount of time is required to observe an object, and a longer or shorter interval must elapse before the impression made by the object on the retina can pass away. If, for example, an individual looks fixedly at the sun for a brief space and darts suddenly into a dark room he sees the sun for a few seconds after entering the dark room. In other words, the impression of the sun remains on the retina of the eye for a few seconds, and, until the image of the sun disappears from the retina, the eye is not in a condition to receive another impression. To take another example : if a horizontal bar with a lighted candle fixed on one end be suspended at its middle by a cord say from the ceiling and be made to revolve slowly, the light is seen as a separate object at any part of the revolution. If, however, the speed be very greatly accelerated a circle of flame only is seen. The

explanation is, that the image produced by the flame on the retina of the eye at one point of the revolution has not time to pass away before fresh images are presented to it, and hence the blurring, mixing up, and continuity of the images resulting in an apparently unbroken circle of flame. Similarly, the spokes of the fly-wheel can be seen as separate objects if the movement be very slow. It is only when the movement is very rapid that the spokes run into each other and become blurred or mixed up so as to present a more or less solid appearance.

It is all a question of time. The natural eye can neither receive nor let go impressions of objects so quickly as the lenses and hyper-sensitive rapid plates of the camera, from which it follows, that the latter can separate or analyse all kinds of rapid movements very much better than the natural eye. Indeed the natural eye can only see the slower movements in mechanics and in animal locomotion. It is reserved for the quick-acting lenses and highly sensitive plates of the camera to see and record the more rapid movements. The camera thus becomes a most powerful and important instrument of investigation in analysing all kinds of quick movements. It is immeasurably superior to every form of sphygmograph or registering apparatus.

Photography is now largely employed in recording the movements of the heavenly bodies, and in supplying minute and reliable details as to changes occurring in the physical universe. Sir Norman Lockyer, a leading authority on spectroscopic work, in a recent lecture, said " that the advance in methods of observation had been so rapid that it was now possible to get spectra of the stars to the third magnitude as good in quality as those obtained of the sun itself twenty years ago. This advance had been mainly due to photography. " Stop photography," said he, " and you stop astronomy as we now understand it." He added, " it was a waste of time for the astronomical student to use his eyes, save to see that his camera, plates, &c., were in perfect working order. By means of photography, millions of facts are accumulated automatically which can be studied subsequently, and such facts are reliable in that they are not biassed by the personality of the observer. . . . In making observations during a total eclipse it is ridiculous to waste one moment in looking at anything."

Mr. Peck, the city astronomer for Edinburgh, in a lecture entitled " How the stars are photographed," delivered in December 1901, stated that during the past fifteen years enormous advances in astronomical photography had been made. Within that time various celestial objects had been revealed by this new method of research (photography), and our knowledge of the sidereal universe greatly extended. The gelatine dry plate, he explained, was of the greatest use in astronomical work, because, while it possessed the greatest sensitiveness to rays of various parts of the spectrum, it could also be given an indefinite length of exposure. Owing to this sensitiveness and accumulative effect of light on the photographic plate, celestial objects which were so faint as to be entirely invisible even with the most powerful telescope, had been shown on the plate. By means of specially devised instruments photographs could actually be obtained of the sun, moon, planets, comets, meteors, stars, and nebulæ. The marvellous results procured by modern photography were as striking as they were unlooked for, and greatly exceeded the dreams of even the most sanguine astronomers." From the foregoing it will be seen that photographs may be taken by very short exposures or instantaneously, and by very long exposures. Short exposure photographs alone can record quick movements ; long exposure photographs suffice for slow moving objects, for still life, and for objects at immeasurably remote distances.

It was at one time thought that instantaneous photography would prove a valuable acquisition to the artist, but this expectation has not been realised. The artist can only portray what he sees and what his fellow-men see. If he attempts to represent the more sudden and jerky movements, say of the limbs of a fast trotting or galloping horse, his drawing becomes an exaggerated caricature of the movements as witnessed by the unaided, natural eye.

The instantaneous pictures produced by the camera lend themselves less to art than to science. Instantaneous photography gives much more accurate representations of animal movements at first hand, than sphygmographic tracings, which are obtained at second hand, and necessitate the intervention of an apparatus capable of generating, extending, and perpetuating error. I have availed myself of instantaneous photography in illustrating the subtleties of several points in locomotion, and have to acknowledge my great indebtedness in this connection to Mr. E. Muybridge.

Mr. Edward Muybridge was one of the first to adopt instantaneous photography in connection with animal locomotion, and this gentleman deserves the highest praise for his industry and enthusiasm in opening up what is practically a new field of research.

He has produced a splendid series of large photographic prints some seven hundred and eighty in number, and containing over twenty thousand figures, representing the locomotion of man, most of the domestic animals, and a large number of wild animals, including birds.

Mr. Muybridge commenced his instantaneous photographs as far back as 1872. In this year, according to his own account, he photographed at Sacramento, California, the famous horse " Occident " while trotting at full speed. The results were not published till 1877. Between 1872 and 1877 he devised an automatic electro-photographic apparatus for the purpose of obtaining consecutive pictures at regulated intervals of time and distance of

horses walking, trotting, galloping, &c. The exposure in certain cases he tells us did not exceed the one five-thousandth part of a second.

These photographs were published in 1878, with the title "The Horse in Motion."

In 1883, the University of Pennsylvania, with great liberality and public spirit, subsidised him to the extent of £5000 or thereby, with a view to his making a comprehensive investigation of "Animal Locomotion" in its widest sense.

For over twenty years Mr. Muybridge has continued his interesting labours, with the result that he has produced a *magnum opus* in photography which finds a fitting resting-place in nearly all the great libraries of the world.

While Mr. Muybridge has produced an unrivalled series of photographs of man and animals, he has not attempted exhaustively to analyse and describe the several animal movements.

Thus in his work "Animals in Motion," published in 1899, he says very little about the walk and the run in man, practically nothing regarding the flight of birds, and comparatively little about the movements of the domestic animals, the horse excepted. He has confined his observations chiefly to the order and sequence of the footfalls of animals, particularly the horse, and to historical notices and references to works of art.

This is not to be wondered at, as he makes no claim to being either an anatomist or a physiologist. Under these circumstances it will excite no surprise if I adhere to my original descriptions and delineations of animal movements published in 1867,[1] 1870,[2] and 1873,[3] long before the account of his instantaneous photographs appeared (1877); and if, further, while supplementing my original descriptions and drawings, I avail myself of certain of his instantaneous photographs which very fully bear out my original conceptions as to how bipeds and quadrupeds walk and run, and birds fly. Mr. Muybridge and I are not in conflict. The explanations given by him of his figures are simply inadequate from the anatomical and physiological point of view. He makes no reference, for example, to the curves, spirals, and figure-of-8 movements made by the extremities of bipeds and quadrupeds, when walking, running, &c. He does not describe the double twisting, diagonal movements which occur at the shoulders and hips in bipeds and quadrupeds whenever and wherever they move; neither does he refer to the spiral configuration of the arms and legs, and the ball-and-socket and spiral joints of the biped and quadruped. He makes no mention of the muscular systems of animals, or of the levers which the bones of the extremities form, or of the pendulum-action of the arms and legs. Lastly, he does not describe or refer to the spiral shape of the wing, or the figure-of-8 movements made by it when the flying animal is fixed, or to the waved tracks made by the wing and the body when the volant animal is flying freely in space.

All these I consider fundamental in animal locomotion, as fully explained by me in the three works referred to.

In employing a selection of Mr. Muybridge's beautiful instantaneous photographs in illustrating my own views I have added vertical and horizontal lines, letters, curved darts, and figures-of-8 where they seemed desirable to bring out my meaning. For these, of course, I am alone responsible. The curved darts, in every instance, indicate the direction in which movement occurs, whether in the trunk or in the limbs.

PROGRESSION ON THE LAND

As the earth, because of its solidity, will bear any amount of pressure to which it may be subjected, the size, shape, and weight of animals destined to traverse its surface are matters of little or no consequence. As, moreover, the surface trod upon is rigid or unyielding, the extremities of quadrupeds are, as a rule, terminated by small feet (Fig. 371. Compare with A, B, C, D, E, of Plate clii., p. 1102).

In this there is a double purpose—the limited area presented to the ground affording the animal sufficient support and leverage, and enabling it to disentangle its feet with the utmost facility, it being a condition in rapid terrestrial progression that the points presented to the earth be few in number and limited in extent, as this approximates the feet of animals most closely to the wheel in mechanics, where the surface in contact with the plane of progression is reduced to a minimum. When the surface presented to a dense resisting medium is increased, speed is diminished, as shown in the tardy movements of the mollusc, caterpillar, and slowworm, and also, though not to the same extent, in the serpents, some of which move with considerable celerity. In the gecko and common house-fly, as is well known, the travelling surfaces are furnished with suctorial discs, which enable those creatures to walk, if need be, in an inverted position; and "the tree-frogs (*Hyla*) have a concave disc at the end of each toe,

[1] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom." (*Transactions of the Linnean Society*, vol. xxvi.)
[2] "The Physiology of Wings." (*Transactions of the Royal Society of Edinburgh*, vol. xxvi.)
[3] "Animal Locomotion, or Walking, Swimming, and Flying." Anglo-American Science Series. London and New York, 1873.

for climbing and adhering to the bark and leaves of trees. Some toads, on the other hand, are enabled, by peculiar tubercles or projections from the palm or sole, to clamber up old walls."[1] A similar, but more complicated arrangement, is met with in the arms of the cuttle-fish.

The movements of the extremities in land animals vary considerably.

In the kangaroo and jerboa,[2] the posterior extremities only are used, the animals advancing *per saltum*, that is, by a series of leaps.[3]

The deer also bounds into the air in its slower movements; in its fastest paces it gallops like the horse. The posterior extremities of the kangaroo are enormously developed as compared with the anterior ones; they are also greatly elongated. The posterior extremities are in excess, likewise, in the horse, rabbit,[4] agouti, and guinea pig. As a consequence these animals descend declivities with difficulty. They are best adapted for slightly ascending ground. In the giraffe the anterior extremities are longer and more powerful, comparatively, than the posterior ones, which is just the opposite condition to that found in the kangaroo.

In the giraffe the legs of opposite sides move together and alternate, whereas in most quadrupeds the extremities move diagonally—a remark which holds true also of ourselves in walking; the right leg and left arm as explained by me in 1867[5] advancing together and forming opposite complemental curves when one step is made; the left leg and right arm also advancing together and forming opposite complemental curves when a second step is made. The legs and arms in walking form diagonal, figure-of-8 curves which cross at every step (see Fig. 302, p. 1078).

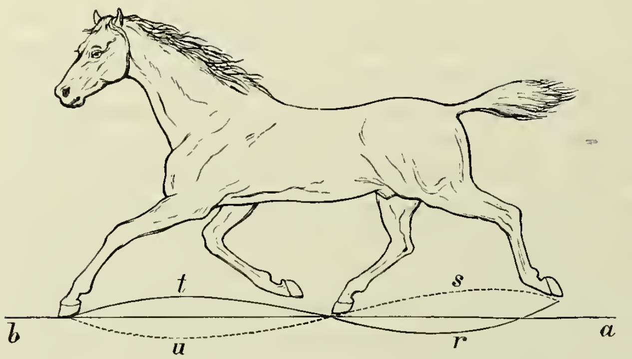


Fig. 371.—Horse trotting. Shows powerful, heavy body, and the small extremities adapted to land transit: also the figure-of-8 movements made by the limbs in the several paces. *t*, *u*, Curves made by the right and left anterior extremities; *s*, *r*, curves made by the right and left posterior extremities. The right fore (*t*) and left hind foot (*r*) move together diagonally to form the waved line (*r*, *t*): the left fore (*u*) and the right hind foot (*s*) move together diagonally to form the waved line (*s*, *u*). The curves formed by the anterior (*t*, *u*) and posterior (*r*, *s*) extremities furnish ellipses which when united give a figure-of-8 trajectory (the Author, 1867, and 1873).

In the hexapod insects, according to Müller, the fore and hind foot of the one side and the middle one of the opposite side move together to make one step, the three corresponding and opposite feet moving together to form the second step. Other and similar combinations are met with in the decapods.

The alternating movements of the extremities are interesting as betokening a certain degree of screwing and twisting in the limbs and trunk, especially at the shoulders and hips. This screwing and twisting begets the figure-of-8 movements observed in walking, swimming, and flying.

In all quadrupeds endowed with great speed, the bones of the extremities, which form the osseous levers in locomotion, are inclined obliquely towards each other to form angles; the angles diminishing as the speed increases. Thus the angles formed by the bones of the extremities with each other and with the scapulæ and iliac bones, are less in the horse than in the elephant. For the same reason they are less in the deer than in the horse. In the elephant, where no great speed is required, the limbs are nearly straight, this being the best arrangement for supporting superincumbent weight. The angles formed by the different bones of the wing of the bird are less than in the fleetest quadruped, the movements of wings being more rapid than those of the extremities of quadrupeds and bipeds. These are so many mechanical adaptations to neutralise shock, to increase elasticity, and secure velocity.

As I cannot hope to analyse the movements of all the animals with terrestrial habits, I will describe only such as illustrate in a progressive manner the more fundamental forms of locomotion.

I naturally begin with the serpent; the spinal column of which, with its muscular cycles, furnishes a key to nearly all the movements which occur in the trunks and limbs of the higher vertebrates. In support of this view it is only necessary to state, that if a cat, when walking, be viewed from above, a double curve or continuous wave of movement is observed to travel along its spine in a direction from before backwards. The movement

[1] "Comp. Anat. and Phys. of Vertebrates," by Professor Owen, vol. i. pp. 262, 263. London, 1866.

[2] The jerboa when pursued can leap a distance of nine feet, and repeat the leaps so rapidly that it cannot be overtaken even by the aid of a swift horse. The bullfrog, a much smaller animal, can, when pressed, clear from six to eight feet at each bound, and project itself over a fence five feet high.

[3] The long, powerful tail of the kangaroo assists in maintaining the equilibrium of the animal prior to the leaps; the posterior extremities and tail forming a tripod of support.

[4] The rabbit occasionally takes several short steps with the fore legs and one long one with the hind legs; so that it walks with the fore legs, and leaps with the hind ones.

[5] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom." *Trans. of the Linn. Soc.*, vol. xxvi.

closely resembled the crawling of the serpent and the swimming of the fish. The double curves, moreover, seen in the spinal column of this most agile of animals reappear in the movements of its extremities.

§ 342. The Creeping of the Serpent.

In this typical vertebrate animal, locomotion is performed by the powerful muscles of the trunk throwing the elongated vertebral column into curves or sinuosities, the free extremities of the numerous ribs, aided by the horny plates on the ventral surface of the body, acting as feet. The movement greatly resembles that of the centipede, if the ribs of the former be made to represent the feet of the latter. As a pair of ribs are supplied to each vertebra, and the ribs, as well as the vertebral column, have their own peculiar muscular cycles, it follows that the movement of the vertebral column of serpents is exceedingly free and practically universal. The vertebral column can, as a matter of fact, be made to move in curves from side to side, and also, though to a much smaller extent, vertically and spirally. A glance at the skeleton of the serpent explains its extraordinary powers of movement (Fig. 372).

The spiral sinuous curves made by the body of the serpent in creeping are due to a co-ordinated, centripetal, and centrifugal action of the intrinsic muscles of the spinal column and ribs, whereby when the muscles on one side of a part of the body shorten or contract, their complemental muscles on the opposite

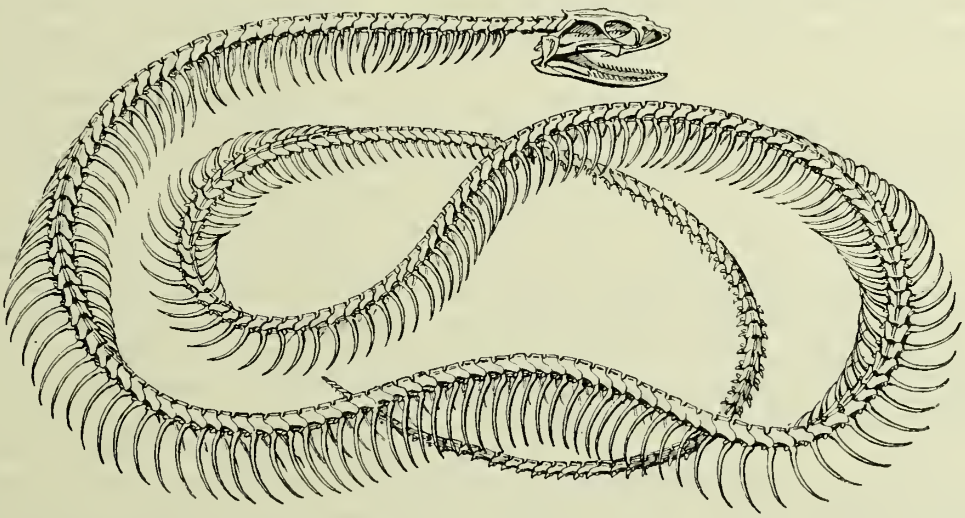


FIG. 372.—Skeleton of ringed snake (*Coluber natrix*). Shows a remarkably mobile spinal column with a multitude of ribs, all of which take part in locomotion (after Dumeril and Bibron).

side of the same part of the body relax or elongate. The movements alternate when opposite curves are made. The sinuous, gliding motion of the serpent utterly precludes the possibility of the muscles of one side of the body forcibly dragging out those of the other side in making the consecutive series of curves necessary to progression. If this arrangement existed the serpent would advance by a series of jerks. The easy, flowing, continuous undulating movements characteristic of the serpent would be impossible. Moreover, the muscles which are all moving at the same instant when the serpent is creeping would have no time alternately and forcibly to drag each other out. The double centripetal and centrifugal action of the muscles on opposite sides of the body becomes a necessity when it is remembered that every part of the body of the serpent is thoroughly under control and capable of forming reverse curves with lightning rapidity. All this means co-ordinated, consentaneous, continuous muscular action so long as it lasts. A precisely similar action occurs in the muscles of the fish when swimming, as will be explained further on.

The muscular and bony arrangements of the serpent give the clue to the structure and movements of the trunk and limbs in the higher vertebrates such as the biped and quadruped. The reader has only to imagine two pairs of limbs developed upon any two opposite, complementary curves made by the body of the serpent in creeping, to realise the diagonal, spiral, twisting movements which occur at the shoulder and hip joints in the walking and other movements of the higher vertebrates. The spiral twisting movements referred to extend also to the extremities, and I shall be able to prove further on that the opposite and complementary curves made by the arms and legs of a man in walking and by the four limbs of a horse and other quadrupeds in walking, trotting, &c., are analogous to, and in a great measure identical with, the opposite and complemental curves made by the serpent in performing its peculiar kind of locomotion.

The serpent in creeping describes a sinuous path on the ground. It does not rear its body into the air on a series of vertical curves like the arches of a bridge, and for a very obvious reason. If it did so there would be no abutment for the ribs and horny ventral plates, and without the ground for an abutment or fulcrum locomotion would be impossible (Fig. 373).

The serpent can raise its head and neck a little and strike its prey when its body is on the ground and when it is coiled up, but it has no power of springing into the air as a whole. It can also when coiled round a tree jerk out its head, neck, and a considerable part of its body to form one or more loops by which it seizes, holds, and crushes its prey.

While the non-poisonous snakes seize and crush their prey, the poisonous ones only bite and poison it. I have watched both modes of attack at the Zoological Gardens, London. The rattlesnakes strike their victims so suddenly that the movements of the head can scarcely be perceived. The pythons, on the contrary, do not bite but seize their victims with lightning rapidity by converting the anterior part of the body into a spiral loop which is quickly tightened on the prey.

The poisonous snakes poison and paralyse their prey and devour it at leisure : the non-poisonous snakes when they once seize their quarry never relax their hold. They, however, cause the loop or loops of their body which have seized and crushed their victim to travel in a backward direction so as to free their head and neck for the purpose of swallowing. This done, the head and neck bend in a backward direction towards the coil or coils containing the prey, which coil or coils in turn move forward towards the head, which they literally feed by pushing the prey into the widely-extended mouth with its re-curved fangs. I have watched the swallowing process in the case of pythons when feeding on rabbits. Their mode of procedure is always the same.

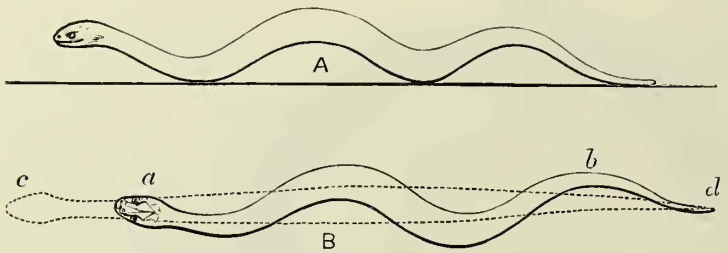


Fig. 373.—A. Shows the serpent as usually but wrongly represented by a series of *vertical* spiral curves.
B. Shows the serpent, as seen in nature, progressing by a series of *lateral* spiral curves, no part of the body being raised from the ground.

The following is the account given of the locomotion of snakes by Dr. Günther : " Snakes are the most stationary of all vertebrates ; as long as a locality affords them a sufficiency of food and some shelter to which they can readily retreat, they have no inducement to change it. Their dispersal, therefore, must have been extremely slow and gradual. Although able to move with extreme rapidity, they cannot maintain the speed for any length of time. Their organs of locomotion are the muscles and ribs, the number of the latter being very great, nearly reaching that of the vertebræ of the trunk. They can adapt their motions to every variation of the ground over which they move, yet all varieties of snake locomotion are founded on a common form of progression. When a part of the body has found some projection of the ground which affords it a point of support, the ribs are drawn more closely together, on alternate sides, thereby producing alternate bends of the body. Similar complemental curves being developed on the anterior portion of the body, these when straightened cause the body to advance. During locomotion the numerous broad shields of the belly are of great advantage, as by means of their free edges the snake is enabled to catch and use as points of support the slightest projections of the ground. A pair of ribs corresponds to each of these ventral shields. Snakes are not able to move over a perfectly smooth surface. Thus it is evident that they move by dragging their body over the ground, or over some other firm base, such as the branch of a tree ;[1] hence the conventional representation of the progress of a snake, in which its undulating body is figured as resting by a series of lower bends on the ground whilst the alternate bends are raised above it, is an impossible attitude. Also the notion that snakes when attacking are able to jump off the ground is quite erroneous ; when they strike an object, they dart the fore part of the body, which was retracted in several bends, forwards in a straight line. And sometimes very active snakes, like the cobra, advance simultaneously with the remainder of their body, which, however, glides in the ordinary fashion over the ground ; but no snake is able to impart such an impetus to the whole of its body as to lose its contact with the ground. Some snakes can raise the anterior part of their body and even move in this attitude, but it is only about the anterior fourth or third of the total length which can thus be erected."

Most of the serpents are excellent swimmers. When they take to the water they throw their bodies into a series of lateral undulations which greatly resemble the undulations made by the eel in swimming. In swimming the functions of the ribs and of the ventral plates are more or less in abeyance.

[1] There are good grounds for believing that serpents when creeping alternately push and pull the several parts of their bodies forwards.

The fact that the serpent can swim as well as creep, and perform various other evolutions, proves that it possesses in its spinal column, ribs, ventral horny plates, and concomitant muscles, the potentialities of locomotion as witnessed in all the higher vertebrates—man included.

Regarding the vertebral column and its muscles as the principal factors of locomotion in the lower vertebrates, it would be convenient at this stage, and in this connection, to describe the swimming of the fish, this, like the creeping of the serpent, depending exclusively on the movements of muscles, acting at first hand, on a simple, symmetrical, flexible spinal column, with its wonderful power of forming curves, spirals, and sinuosities of every description.

If, however, I described the swimming of the fish here, I would have to mix up locomotion on the land with locomotion on and in the water, which I am anxious to avoid. I will therefore proceed with the locomotion of bipeds and quadrupeds where highly developed limbs are present, and where their movements are confined to the land. The swimming of the fish will be described further on.

It may be interesting to state before leaving this subject that even a spinal column is not absolutely necessary to locomotion, as witness the locomotion of the tadpole, immature fishes as a class, and certain adult rudimentary fishes. "The lowermost sub-class of fishes, which comprises one form only, the Lancelet (*Branchiostoma* [*s. Amphioxus*] *lanceolatum*), possesses a skeleton of the most primitive type. The vertebral column is represented by a simple *chorda dorsalis* or *notochord* only, which extends from one extremity of the fish to the other, and, so far from being expanded into a cranial cavity, it is pointed at its anterior end as well as at its posterior. It is enveloped in a simple membrane like the spinal cord and the abdominal organs, and there is no trace of vertebral segments or ribs; however, a series of short cartilaginous rods above the spine evidently represent apophyses. A maxillary or hyoid apparatus, or elements representing limbs, are entirely absent.

"The skeleton of the *Cyclostomata* (or *Marsipobranchii*) (lampreys and sea-hags) shows a considerable advance of development. It consists of a notochord, the anterior pointed end of which is wedged into the base of a cranial capsule, partly membranous, partly cartilaginous. This skull, therefore, is not movable upon the spinal column. No vertebral segmentation can be observed in the notochord, but neural arches are represented by a series of cartilages on each side of the spinal cord."

Some of the old-world fishes were also deficient as regards a backbone. "Of the ganoid fishes, the family *Palæoniscidæ* (Traquair) is numerously represented; others are *Cœlacanths* (*Cœlacanthus rhizodus*), and *Saurodipteridæ* (*Megalichthys*). None of these fishes have an ossified vertebral column, but in some (*Megalichthys*) the outer surface of the vertebræ is ossified into a ring; the termination of their tail is heterocercal."[1] The heterocercal or unequally lobed tail is essentially an old-world form. It persists in the modern shark tribe, and is a very powerful swimming organ.

§ 343. The Locomotion of Birds—the Ostrich.

Birds have been divided by naturalists into eight orders: The *Natatores*, or swimming birds; the *Grallatores*, or wading birds; the *Cursores*, or running birds; the *Scansores*, or climbers; the *Rasores*, or scrapers; the *Columbæ*, or doves; the *Passeres*; and the *Raptores*, or birds of prey.

The first five orders have been classified according to their habits and modes of progression. The *Natatores* I shall consider when I come to speak of swimming as a form of locomotion, and as there is nothing in the movements of the wading, scraping, and climbing birds,[2] or in the *Passeres*[3] or *Raptores*, requiring special notice, I proceed at once to a consideration of the *Cursores*, the best examples of which are the ostrich, emu, cassowary, and apteryx.

The ostrich is remarkable for the great length and development of its legs as compared with its wings (Fig. 374). In this respect it is among birds what the kangaroo is among mammals. The ostrich attains a height of from six to eight feet, and is the largest living bird known.[4] Its great height is due to its attenuated neck and legs. The latter are very powerful structures, and greatly resemble in their general conformation the posterior extremities of a thoroughbred horse or of one of the larger deer—compare with Figs. 344 and 420, pp. 1093, 1133. They are expressly made for speed. Thus the bones of the leg and foot are inclined very obliquely towards each other, the femur being inclined very obliquely to the ilium. As a consequence, the angles made by the several bones of the legs are comparatively small; smaller in fact than in either the horse or the deer.

The feet of the ostrich, like those of the horse and deer, are reduced to a minimum as regards size; so that they occasion very little friction in the act of walking and running. The foot is composed of two jointed toes[5]

[1] "The Study of Fishes," by Albert C. L. G. Günther, M.A., M.D., F.R.S., 1880, pp. 63 and 64.
[2] The woodpeckers climb by the aid of the stiff feathers of their tails; the legs and tail forming a firm basis of support.
[3] In this order there are certain birds—the sparrows and thrushes, for example—which advance by a series of vigorous leaps; the leaps being of an intermitting character.
[4] The extinct moa (*Dinornis giganteus*) attained a height of from fourteen to fifteen feet.
[5] The toes in the emu amount to three.

which spread out, when the weight of the body comes upon them, in such a manner as enables the bird to seize and let go the ground with equal facility. The advantage of such an arrangement in rapid locomotion cannot be over-estimated. The elasticity and flexibility of the foot contribute greatly to the rapidity of movement for which this celebrated bird is famous. The limb of the ostrich, with its large bones placed very obliquely to form a system of powerful levers, is the very embodiment of speed. The foot is quite worthy of the limb, it being in some respects the most admirable structure of its kind in existence. The foot of the ostrich differs considerably from that of all other birds, those of its own family excepted. Thus the under portion of the foot is flat, and specially adapted for acting on plane surfaces, particularly solids.[1] The extremities of the toes superiorly are armed with powerful short nails, the tips of which project inferiorly to protect the toes and confer elasticity when the foot is leaving the ground. The foot, like the leg, is remarkable for its great strength. The legs of the ostrich are closely set, another feature of speed.[2] The wings of the ostrich are in a very rudimentary condition as compared with the legs.[3] All the bones are present, but they are so dwarfed that they are useless as organs of flight. The angles which the bones of the wing make with each other are still less than the angles made by the bones of the leg. This is just what we would *a priori* expect, as the velocity with which wings are moved greatly exceeds that with which legs are moved. The bones of the wing of the ostrich are inclined towards each other at nearly right angles. The wings of the ostrich, although useless as flying organs, form important auxiliaries in running. When the ostrich careers along the plain, it spreads out its wings in such a manner that they act as balancers and kites, and so enable it to maintain its equilibrium and diminish its weight. The wings, because of the angle of inclination which their under surfaces make with the horizon, and the great speed at which the ostrich travels, act as true kites, and so elevate and carry forward by a mechanical adaptation a certain proportion of the mass of the bird already in motion. The elevating and propelling power of even diminutive inclined planes is very considerable when carried along at a high speed in a horizontal direction.

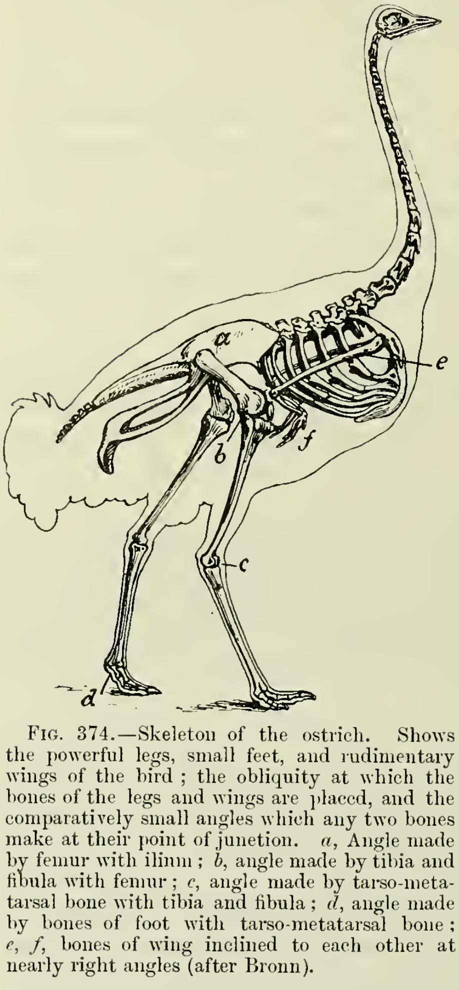


Fig. 374.—Skeleton of the ostrich. Shows the powerful legs, small feet, and rudimentary wings of the bird; the obliquity at which the bones of the legs and wings are placed, and the comparatively small angles which any two bones make at their point of junction. *a*, Angle made by femur with ilium; *b*, angle made by tibia and fibula with femur; *c*, angle made by tarso-metatarsal bone with tibia and fibula; *d*, angle made by bones of foot with tarso-metatarsal bone; *e*, *f*, bones of wing inclined to each other at nearly right angles (after Bronn).

If an oblong sheet of cardboard held in the hand, at an upward angle, be thrust out of the window of the carriage of an express train in motion, the amount of elevating power developed is quite remarkable. If the cardboard be made to rise and fall in imitation of the wing movements, the kite-action of the wing during the up and down strokes is exemplified in a striking and convincing manner.

I have frequently performed this experiment with an ordinary newspaper folded up to resemble the blade of a cricket bat.

The wings of the ostrich in addition to their elevating and propelling power contribute, by their short, rapid, swinging movements, to continuity of motion in the legs. No bird with large wings can run well. The albatross, for example, walks with difficulty, and the same may be said of the vulture and eagle. What, therefore, appears a defect in the ostrich is a positive advantage when its habits and mode of locomotion are taken into account.

Professional runners in many cases at matches reduce the length of their anterior extremities by flexing their arms and carrying them on a level with their chest. It would seem that in rapid running there is not time for the arms to oscillate naturally, and that under these circumstances the arms, if allowed to swing about, retard rather than increase the speed. The centre of gravity is well forward in the ostrich, and is regulated by the movements of the head and neck, and the obliquity of the body and legs. In running the neck is stretched, the body inclined forward, and the legs moved alternately and with great rapidity. When the right leg is flexed and elevated, it swings forward pendulum-fashion, and describes a curve whose convexity is directed towards the right side. When the left leg is flexed and elevated, it swings forward and describes a curve whose convexity is directed towards the left side. The curves made alternately by the right and left leg form when united a waved line (*vide* Fig. 302, p. 1078).

[1] Feet designed for swimming, grasping trees, or securing prey, do not operate to advantage on a flat surface. The awkward waddle of the swan, parrot, and eagle when on the ground affords illustrations.
[2] In draught horses the legs are much wider apart than in racers; the legs of the deer being less widely set than those of the racer.
[3] In the Apteryx the wings are so very small that the bird is commonly spoken of as the "wingless bird."

When the right leg is flexed, elevated, and advanced, it rotates upon the iliac portion of the trunk of the bird ; the trunk being supported for the time being by the left leg, which is extended, and in contact with the ground. When the left leg is flexed, elevated, and advanced, it, in like manner, rotates upon the iliac portion of the trunk, which in this instance is supported by the extended right leg. The leg which is on the ground for the time being supplies the necessary lever, the ground the fulcrum. When the right leg is flexed and elevated, it rotates upon the iliac portion of the trunk in a forward direction, the right foot describing the arc of a circle. When the right leg and foot are extended and fixed on the ground, the trunk rotates upon the right foot in a forward direction to form the arc of a circle, which is the converse of that formed by the right foot. If the arcs alternately supplied by the right foot and trunk are placed in opposition, a more or less perfect vertical circle is produced, and thus it is that the locomotion of animals is approximated to the wheel in mechanics. Similar remarks are to be made of the left foot and trunk. The alternate rolling of the trunk on the extremities, and the extremities on the trunk, utilises or works up the inertia of the moving mass, and powerfully contributes to continuity and steadiness of action in the moving parts. By advancing the head, neck, and anterior parts of the body, the ostrich inaugurates the rolling movement of the trunk, which is perpetuated by the rolling movements of the legs. The trunk and legs of the ostrich are active and passive by turns. The movements of the trunk and limbs are definitely co-ordinated. But for this reciprocation the action of the several parts implicated would neither be so rapid, certain, nor continuous. The speed of the ostrich exceeds that of every other land animal, a circumstance due to its long, powerful legs and great stride. It can outstrip without difficulty the fleetest horses, and is only captured by being simultaneously assailed from various points, or run down by a succession of hunters on fresh steeds. If the speed of the ostrich, which only measures six or eight feet, is so transcending, what shall we say of the speed of the extinct *Æpyornis maximus* and *Dinornis giganteus*, which are supposed to have measured from fourteen to fifteen feet in height ? Incredible as it may appear, the ostrich, with its feet reduced to a minimum as regards size, and peculiarly modified for walking and running on solids, can also swim. Mr. Darwin informs us that ostriches take to the water readily, and not only ford rapid rivers but also cross from island to island. They swim leisurely, with neck extended, and the greater part of the body submerged.

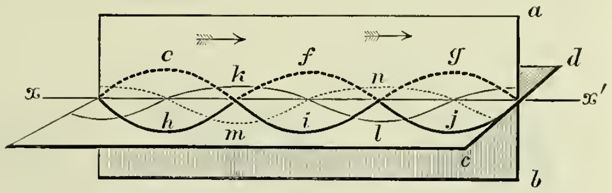


Fig. 375.—Shows that locomotion in the biped and quadruped is effected by curved pendulum movements occurring in more or less vertical and horizontal planes : the movements running into each other to form waved oblique figure-of-8 trajectories (the Author, 1867, 1872, and 1873).

The vertical and lateral horizontal curves made by the feet and trunk of the ostrich and of bipeds and quadrupeds in walking and running, which, when united, form oblique figure-of-8 trajectories, are given at Fig. 375.

In the above figure (375) *a*, *b*, indicate the vertical and *c*, *d*, the lateral or horizontal plane of movement ; *e*, *f*, *g*, refer to the lateral horizontal curves formed by the left leg and foot if they be made simply to oscillate pendulum-fashion as apart from walking ; *h*, *i*, *j*, those made by the right leg and foot under similar circumstances. *h*, Represents the curve made by the right leg, and *e*, that made by the left arm, which advance together to form one step ; *i*, the curve formed by the right arm, and *f*, that formed by the left leg, which advance together to form a second step ; *j*, the curve made by the right leg, and *g*, that made by the left arm, which advance together to form a third step. At *k*, *n*, the vertical or upward curves made by the trunk when it rolls forward on the foot placed on the ground for the time being are given ; and at *m*, *l*, the downward curves made by the foot when the leg rolls forward pendulum-fashion on the iliac portion of the pelvis are seen. *x*, *x'*, Represent the axis of motion, and the darts the direction of motion. This figure (375) gives an accurate representation of the movements made by the limbs, feet, and trunk of bipeds when walking and running. It also shows how the feet, limbs, and trunks of quadrupeds form oblique figure-of-8 trajectories when walking, running, and galloping.

The walking of the ostrich as depicted by instantaneous photography is given at Figs. 376 to 381 inclusive. The darts introduced by me indicate the curves made by the limbs and feet, and the direction of the movements in walking and running.

Fig. 376 represents the ostrich with both feet on the ground, the left leg and foot being slightly flexed or bent and about to leave the ground to make a step forward.

Fig. 377 represents the left leg and foot considerably flexed, off the ground, and in the act of swinging forward in a curve pendulum-fashion (see curved dart).

Figs. 378, 379, and 380 show a continuation of the same movement, the flexion of the left leg and foot in Figs. 379 and 380 becoming less than in Fig. 378 preparatory to placing the left foot on the ground.

At Fig. 381 the left leg is extended and the left foot firmly placed on the ground, and one step completed.

This figure (381) also shows the right leg and foot flexed and elevated and about to begin a second step (see curved dart).

The second step, as made by the right leg and foot in the adjutant, is given at Figs. 382 to 387 inclusive.

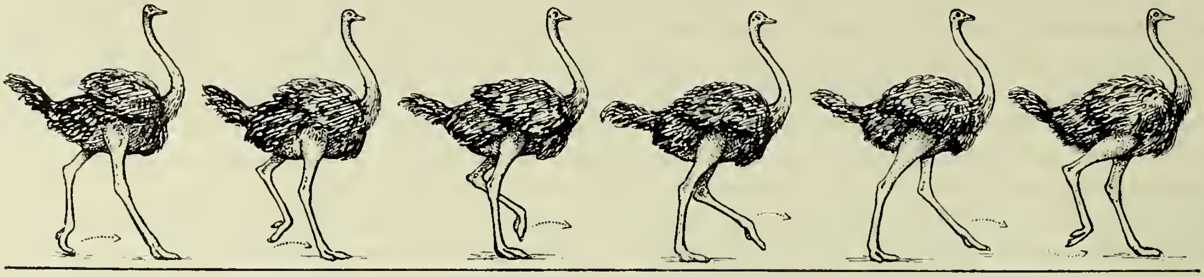


Fig. 376. Fig. 377. Fig. 378. Fig. 379. Fig. 380. Fig. 381.

Figs. 376 to 381.—Show curved pendulum movements in two planes made by the left leg and foot, and the body of the ostrich in walking.

It will be observed that in both the ostrich and the adjutant the leg which is flexed or bent, off the ground, and swinging forward in space, performs pendulum movements ; these movements being peculiar in that they describe more or less vertical and lateral horizontal curves at one and the same time. As a matter of fact they describe

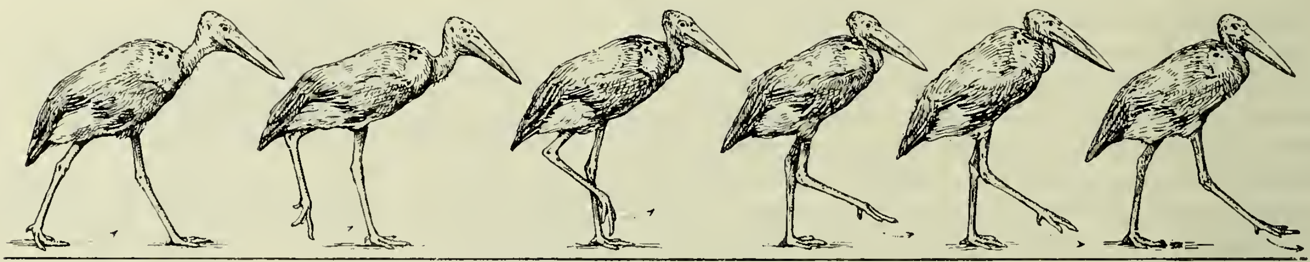


Fig. 382. Fig. 383. Fig. 384. Fig. 385. Fig. 386. Fig. 387.

oblique spiral curves not confined to one plane. The forward roll of the body on the leg which happens to be on the ground for the time being is also indicated in the walk of the ostrich and adjutant.

The forward screwing diagonal curves made by the legs, feet, trunk, shoulders, haunches, neck, and head of the ostrich, when running, are given at Figs. 334 and 335, p. 1088 (see curved darts *a*, *b*, and *c*, *d* ; compare with Fig. 338, p. 1088).

The locomotion of the ostrich and adjutant, especially the former, forms a fitting introduction to the locomotion of man.

§ 344. Locomotion in Man.

Man is properly regarded as the paragon of animals, and this estimate applies equally to his physical powers and his mental attributes.[1] It is with the former we have more especially to do in the present connection. The skeleton in man is delicately and daintily modelled, but possessed of great strength, and the muscular system is highly developed, and presents a contour which for beauty of outline, adaptation, and power cannot be surpassed. There is no kind of physical feat which man cannot perform, and he is as far ahead of the animals in this respect as he towers above them in intellectual capacity.

In gymnastic feats he excels even the monkeys whose lives are largely devoted to such exercises. His hands and feet are especially admirable structures. The former enable him to perform the most delicate operations and to construct the most wonderful and complicated machines large and small ; they are the instruments to which all the arts owe their existence. But for his marvellously perfect hands the intellect of man would be more or less an abstraction. The head and hand are correlated as no other parts of the body are. The human hand is a masterpiece of design. The human foot in some respects is scarcely inferior. It is capable of the most varied and delicate movements, and can be trained to do nearly all that the hand does ; to paint, to write, to use edged tools, to convey food to the mouth, &c. The foot is the chief organ of locomotion, and it displays a fitness for this particular kind of work which cannot be too much admired. The bones of the foot are arranged in a double

[1] "What a piece of work is a man ? How noble in reason ! how infinite in faculties ! in form and moving, how express and admirable ! in action, how like an angel ! in apprehension, how like a god ! " Shakespeare, "Hamlet," Act ii., Sc. 2.

arch which is more or less skewed, namely, an antero-posterior and lateral arch, the one gradually merging into the other; an arrangement which at once secures strength and elasticity. The elastic properties of the foot, which confer spring upon it, are due to the presence of a large number of small bones each with a modicum of movement; a disposition of parts which admits of a limited amount of yielding to enable the foot to adapt itself to unequal surfaces and so prevent shock and injury. A well-made foot is capable of enormous exertion and endurance, and thousands of miles may be traversed by it without discomfort provided it is properly protected, and due intervals of rest allowed.

The foot is furnished with its own intrinsic muscles and tendons, in addition to the muscles and tendons supplied to it by the leg. Altogether it is very bountifully endowed both as regards bones, muscles, and tendons, and but for its many physical perfections it would be altogether inadequate to perform the many complicated and important movements which it is called upon to discharge (Fig. 291, p. 1057).

The osseous and muscular systems in man are best considered together, but no elaborate descriptions of either are required for the purposes of locomotion.

The skeleton and the muscles moving it are to be regarded as complemental, co-ordinated structures, and they are to be considered in their entirety rather than in piecemeal fashion, that is, in detached portions or areas (Figs. 254 and 255, p. 1030). Muscles rarely act individually. As a rule they act simultaneously in co-ordinated sets. But for this arrangement voluntary movements and locomotion would be alike impossible. Voluntary movements and locomotion are equally the result of training, and much and steady training is required to educate the arms and hands to perform the various functions assigned to them in the arts of peace and war. In like manner the legs and feet have to be educated to walk and run. This education, so irksome and laborious, consists in training the various muscles and bones to act in concert in order to accomplish given ends promptly and effectively. It would avail nothing to train one muscle and one bone. The osseous and muscular systems consist of many parts, and their actions are co-ordinated and grouped. Voluntary movement in any part or region of the body is the result of co-ordinated muscular cycles acting consentaneously on given bones and joints which are so constructed and so arranged that they give effect to, and emphasise, the muscular movements. The muscles and bones are so exquisitely adjusted to each other that a fine poise or balance is always maintained and no power lost. The muscles and bones never war against each other. The muscles alternately exert a centripetal and centrifugal power in moving the bones, and in virtue of this double power the bones can literally be moved to a hair's-breadth. When one set of muscles exert their centrifugal power or elongate (relax), the complementary set exert their centripetal power or shorten (contract); the bones placed between the two sets of muscles being made to move and vibrate with the utmost exactitude. The delicate, rapid, vibratory movements of muscles and bones are seen to perfection in the bird's wing during flight. An animal with a highly developed, differentiated muscular and bony system can act instantly in whole or in part. It represents a living mass, every part of which is directly or indirectly under control. It acts under the influence of the will, and its movements are in no sense regulated by external stimulation or outside influences. By regarding the osseous and muscular systems as wholes an animal is free to move at discretion. It has the whip hand of the situation and can regulate its every movement with a degree of nicety otherwise unattainable. An educated, trained muscular system makes no mistakes. When it has once obtained the mastery of itself by frequent efforts and repetition it acts more or less automatically, but always correctly. All these arrangements, which are means to ends, betoken design. The movements in question begin *in utero* before they are under the influence of the will, and the so-called involuntary movements are not under the control of the will even in adults. The movements of the chest, heart, stomach, alimentary canal, bladder, uterus, &c., furnish examples of involuntary movements. It is not possible to draw a sharp line of demarcation between voluntary and involuntary movements; the one runs into the other under certain circumstances and conditions, and movements which are voluntary in sane persons not unfrequently become involuntary in insane persons.

The cerebro-spinal nervous system exerts a regulating, controlling power in the case of voluntary muscles, and the sympathetic nervous system in the case of involuntary muscles. Muscles in the higher animals are always associated with nerves, as they are associated with bones, and the three act consentaneously and together to overtake the work of the body whether that be voluntary or involuntary in its nature.

This explains why locomotion may be intelligent or automatic, or partly the one and partly the other. A man may walk and run with or without thinking when he has once acquired the art of walking and running.

While the osseous and muscular systems are best treated together, it is convenient to examine them separately. I therefore give separate illustrations of the human skeleton, and of the human voluntary muscular system. As the skeleton affords points of attachments (origins and insertions) to the voluntary muscles, and at the same time forms a supporting structure, I begin with it.

A fine representation of the human skeleton is given at Fig. 388.

The speed attained by man, although considerable, is not remarkable. It depends on a variety of circumstances, such as the height, age, sex, and muscular energy of the individual, the nature of the surface passed over, and the resistance to forward motion due to the presence of air, whether still or moving. A reference to the human skeleton, particularly its inferior extremities, will explain why the speed should be moderate.

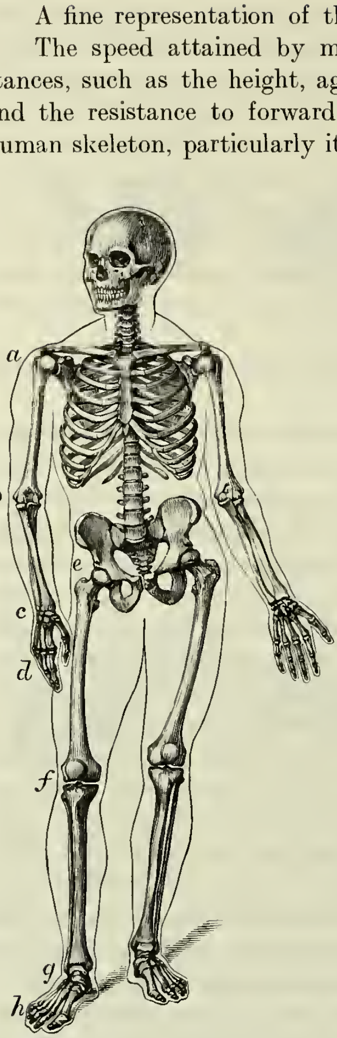


Fig. 388.—Skeleton of man *a*, Ball-and-socket joint of shoulder; *b*, spiral elbow joint; *c*, spiral wrist joint; *d*, spiral hand joints, as seen in the right arm and hand. The bones of the arm, forearm, and hand are all more or less spiral. The radius is seen twisting round the ulna between *b* and *c*. Compare with the foreleg of the elephant and the wing of the bird (Fig. 105, A and B. p. 1079); *e*, ball-and-socket joint of hip; *f*, spiral knee joint; *g*, spiral ankle joint; *h*, spiral foot joints, as seen in the right leg. The bones of the legs, like those of the arms, are all distinctly spiral. The contour of the body is indicated by the faint outline investing the skeleton (after Leveillé).

On comparing the inferior extremities of man with the legs of birds, or the posterior extremities of quadrupeds, say the horse or deer, we find that the bones composing them are not so obliquely placed with reference to each other, neither are the angles formed by any two bones so acute. Further, we observe that in birds and quadrupeds the tarsal and metatarsal bones are so modified that they form additional angles. In the extremities of birds and quadrupeds there are four angles, which may be increased or diminished in the operations of locomotion. Thus, in the quadruped and bird the femur forms with the ilium one angle; the tibia and fibula with the femur a second angle; the cannon or tarso-metatarsal bone with the tibia and fibula a third angle; and the bones of the foot with the cannon or tarso-metatarsal bone a fourth angle. In man the bones of the legs only form three angles. The absence of the fourth angle is due to the fact that in man the tarsal and metatarsal bones are shortened and crowded together; whereas in the quadruped and bird they are elongated and separated.

As the speed of a limb increases in proportion to the number and acuteness of the angles formed by its several bones, it is not difficult to understand why man should not be so swift as the majority of quadrupeds. The increase in the number of angles increases the power which an animal has of shortening and elongating its extremities, and the levers which the extremities form. To increase the length of a lever is to increase its power at one end, and the distance through which it moves at the other; hence the faculty of bounding or leaping possessed in such perfection by many quadrupeds.[1] If the wing be considered as a lever, a small degree of motion at its root produces an extensive sweep at its tip. It is thus that the wing is enabled to work up and utilise the thin medium of the air as a buoying medium.

The manner in which the angles formed by the bones of the limbs are increased and diminished, and the limbs themselves elongated and shortened, is readily understood from the following mechanical arrangement (lazy tongs) which readily admits of the angles being increased and diminished (Fig. 389 A, B).

Another drawback to great speed in man is his erect position. Part of the power which should move the limbs is devoted to supporting the trunk. For the same reason the bones of the legs, instead of being obliquely inclined to each other, as in the quadruped and bird, are arranged in a nearly vertical spiral line. This arrangement increases the angle formed by any two bones, and, as a consequence, decreases the speed of the limbs, as explained. A similar disposition of the bones is found in the anterior extremities of the elephant (Plate cl., Fig. 2, p. 1028), where the superincumbent weight is great, and the speed, considering the immense size of the animal, not remarkable. The bones of the human leg are beautifully adapted to sustain the weight of the body and neutralise shock.[2] Thus the femur or thigh bone is furnished at its upper extremity with a ball-and-socket joint which unites it to the cup-shaped depression (acetabulum) in the ilium (hip bone). It is supplied with a neck which carries the body or shaft of the bone in an oblique direction from the ilium, the shaft being arched forward and twisted upon itself to form an elongated cylindrical screw. The lower portion of the femur is furnished with spiral articular surfaces accurately adapted to the upper portions of the bones of the leg, namely, the tibia and fibula, and to the patella. The bones of the leg (tibia and fibula) are spirally arranged; the screw in this instance being split up. At the ankle the bones of the leg are applied to those of the foot by spiral articular surfaces analogous to those found at the knee-joint.

1 "The posterior extremities in both the lion and tiger are longer, and the bones inclined more obliquely to each other than the anterior, giving them greater power and elasticity in springing."

2 "The pelvis receives the whole weight of the trunk and superposed organs, and transmits it to the heads of the femurs."

The weight of the trunk is thus thrown on the foot, not in straight lines, but in a series of curves. The foot itself is wonderfully adapted to receive the pressure from above. It consists of a series of small bones (the tarsal, metatarsal, and phalangeal bones), arranged in the form of a double arch ; the one arch extending from the heel towards the toes, the other arch across the foot (Figs. 290 and 291, pp. 1057). The foot is so constructed that it is at once firm, elastic, and movable,—qualities which enable it to sustain pressure from above, and exert and transmit pressure from beneath. In walking, the heel first reaches and first leaves the ground. When the heel is elevated the weight of the body falls more and more on the centre of the foot and toes, the latter spreading out[1] as in birds to seize the ground and lever the trunk forward. It is in this movement that the wonderful mechanism of the foot is displayed to most advantage, the multiplicity of joints in the foot all yielding a little to confer that elasticity of step which is so agreeable to behold, and which is one of the characteristics of youth. The foot may be said to roll over the ground in a direction from behind forwards. I have stated that the angles formed by the bones of the human leg are larger than those formed by the bones of the leg of the quadruped and bird. This is especially true of the angle formed by the femur with the ilium, which, because of the upward direction given to the crest of the ilium in man, is so great that it virtually ceases to be an angle.

The bones of the superior extremities in man merit attention from the fact that in walking and running they oscillate in opposite directions diagonally, and alternate and keep time with the legs ; the right arm advancing with the left leg, while the left arm swings back ; the left arm advancing with the right leg while the right arm swings back. There is this difference. The arms oscillate and have a forward and backward movement ; the legs always advance.

The arms are articulated at the shoulders by ball-and-socket joints to cup-shaped depressions (glenoid cavities) closely resembling those found at the hip joints (Fig. 270, A, B, p. 1043). The bone of the arm (humerus) is carried away from the shoulder by a short neck, as in the thigh bone (femur). Like the thigh bone it is twisted upon itself and forms a screw. The lower end of the arm bone is furnished with spiral articular surfaces resembling those found at the lower end of the femur which take part in the formation of the knee-joint. The spiral articular surfaces of the arm bone are adapted to similar surfaces existing on the upper ends of the bones of the forearm, to wit, the radius and ulna. They assist in the formation of the elbow joint. The bones of the forearm are spirally disposed with reference to each other, and form a screw consisting of two parts ; the radius rotating and twisting round the ulna in pronation and supination.

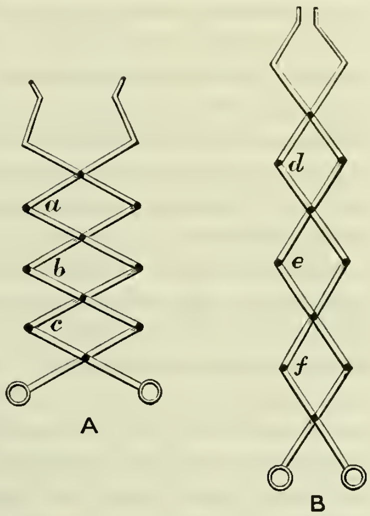


Fig. 389.—A. Shows that if the handle of the lazy tongs be separated the angles (*a*, *b*, *c*) formed by their component parts or by the bones of the limb are acute or small angles. In this case the limb is flexed and shortened.
B. Shows that if the handles of the tongs be drawn together the angles (*d*, *e*, *f*) formed by their component parts or by the bones of the limb are obtuse or large angles. In this case the limb is extended and elongated. Compare with Figs. 421, 422, and 423 (the Author).

The bones of the forearm are united to those of the wrist (carpal) and hand (metacarpal and phalangeal) by articular surfaces displaying a greater or less degree of spirality. From this it follows that the superior extremities of man greatly resemble his inferior ones ; a fact of considerable importance, as it accounts for the part taken by the superior extremities in locomotion. In man the arms do not touch the ground as in the brutes, but they do not on this account cease to be useful as instruments of progression. If a man walks with a stick in each hand the movements of his extremities exactly resemble those of a quadruped.

These points are readily made out by a reference to the human skeleton. For illustrations of spiral bones and joints in the elephant and in man see Plate cl., Figs. 1, 2, 3, and 4, p. 1028.

The bones of the human extremities (superior and inferior) are seen to advantage in Fig. 388 ; and I particularly direct the attention of the reader to the ball-and-socket or universal joints by which the arms are articulated to the shoulders (*a*), and the legs to the pelvis (*e*), as a knowledge of these is necessary to a comprehension of the oscillating or pendulum movements of the limbs now to be described. But for the ball-and-socket joints, and the spiral nature of the bones and articular surfaces of the extremities, the undulating, sinuous, and more or less continuous movements observable in walking and running, and the twisting, lashing, flail-like movements necessary to swimming and flying, would be impossible.

The leg in the human subject is supplied with three joints, namely, the hip (*e*), knee (*f*), and ankle (*g*) joints. When standing in the erect position on one leg, the hip joint permits the free limb to move forwards and back-

[1] The spreading action of the toes is seen to perfection in children. It is more or less destroyed in adults from a faulty principle in boot and shoemaking, the soles being invariably too narrow.

wards, outwards and inwards, and also to rotate or circumduct; the knee-joint admits of backward and forward movement, and the ankle-joint of upward and downward, and outward and inward movements. When the body or limbs are inclined obliquely, or slightly flexed, the range of motion is increased.

The greatest angle made at the knee-joint is equal to the sum of the angles made by the hip and ankle joints when these joints are simultaneously flexed, and when the angle of inclination made by the foot with the ground equals 30°.

From this it follows that the trunk maintains its virtually erect position during the extension and flexion of the limbs. The step in walking was divided by Borelli into two periods, the one corresponding to the time when both limbs are on the ground; the other when only one limb is on the ground. In running, there is a brief period when both limbs are off the ground. In walking, the body is alternately supported by the right and left legs, and advanced by a sinuous movement. Its forward motion is quickened when one leg is on the ground, and slowed when both are on the ground. When the limb (say the right leg) is flexed, elevated, and thrown forward, it returns if left to itself (that is, if its movements are not interfered with by the voluntary muscles) to the position from which it was moved, namely, the vertical, unless the trunk bearing the limb is inclined in a forward direction at the same time. The limb returns to the vertical position, or position of rest, in virtue of the power exercised by gravity, and from its being hinged at the hip by a ball-and-socket joint, as explained. In this respect the human limb when allowed to oscillate exactly resembles a pendulum—a fact first ascertained by the brothers Weber. The advantage accruing from this arrangement, as far as muscular energy is concerned, is very great, the muscles doing comparatively little work.[1] In beginning to walk, those portions of the body and limb which are to take the first step are advanced together. When, however, the body is inclined forwards, a large proportion of the step is performed mechanically by the tendency which the pendulum formed by the leg has to swing forward and regain a vertical position, an effect produced by the operation of gravity alone. The leg which is advanced swings further forward than is required for the step, and swings back a little before it can be deposited on the ground. The pendulum movement effects all this mechanically. When the limb has swung forward as far as the inclination of the body at the time will permit, it reverses, pendulum fashion; the back stroke of the pendulum actually placing the foot upon the ground by a retrograde, descending movement. When the right leg with which we commenced is extended and firmly placed upon the ground, and the trunk has assumed a nearly vertical position, the left leg is flexed, elevated, and the trunk once more bent forward. The forward inclination of the trunk necessitates the swinging forward of the left leg, which, when it has reached the point permitted by the pendulum movement, swings back again to the extent necessary to place it securely upon the ground. These movements are repeated at stated and regular intervals. The retrograde movement of the limb is best seen in slow walking. In fast walking the pendulum movement is somewhat interrupted from the limb being made to touch the ground when it attains a vertical position, and therefore before it has completed its oscillation.[2] The swinging forward of the body may be said to inaugurate the movement of walking. The body is slightly bent and inclined forwards at the beginning of each step. It is straightened and raised towards the termination of that act. The movements of the body begin and terminate the steps, and in this manner regulate them. The trunk rises vertically at each step, the head describing a slightly upward curve well seen in the walking of birds.

When the right foot is fixed on the ground and a step is being made by the left foot, the left leg is flexed and the left shoulder elevated; the elevation of the left shoulder facilitating the flexion of the left leg. Conversely, when the left foot is fixed on the ground and a step is being made by the right foot, the right leg is flexed and the right shoulder elevated. The alternating raising and depressing of the right and left shoulders correspond with the flexion and extension of the limbs in walking and running, and are due to a twisting, diagonal movement which occurs partly in the hips and partly in the shoulders, as shown at Fig. 328, p. 1087.

The trunk and limbs are active and passive by turns. In walking, a spiral wave of motion, most marked in an antero-posterior direction (although also appearing laterally), runs through the spine. This spiral spinal movement is observable in the locomotion of all vertebrates. It is emphasised in man by the antero-posterior curves (cervical, dorsal, and lumbar) existing in the human vertebral column. In the effort of walking the trunk and limbs oscillate on the ilio-femoral articulations (hip-joints). The trunk also rotates in a forward direction on the foot which is placed upon the ground for the time being. The rotation begins at the heel and terminates at the toes. So long as the rotation continues, the body rises. When the rotation ceases, and one foot is placed flat upon the ground, the body falls. The elevation and rotation of the body in a forward direction enable the foot which is off the ground for the time being to swing forward, pendulum fashion. The swinging foot, when it can oscillate no further in a

[1] The brothers Weber found that so long as the muscles exert the general force necessary to execute locomotion, the velocity depends on the size of the legs and on external forces, but *not on the strength of the muscles.*

[2] "In quick walking and running the swinging leg never passes beyond the vertical which cuts the head of the femur."

forward direction, reverses its course and retrogrades to a slight extent, at which juncture it is deposited on the ground, as explained. The retrogression of the swinging foot is accompanied by a slight retrogression on the part of the body, which tends at this particular juncture to regain a vertical position. From this it follows that in slow walking the trunk and the swinging foot advance together through a considerable space, and retire through a smaller space ; that when the body is swinging it rotates upon the ilio-femoral articulations (hip-joints) as an axis ; and that when the leg is not swinging, but fixed by its foot upon the ground, the trunk rotates upon the foot as an axis. These movements are correlated and complementary in their nature, and are calculated to relieve the muscles of the legs and trunk engaged in locomotion from excessive wear and tear.

Similar movements occur in the arms, which, as has been explained, are articulated to the shoulders by ball-and-socket joints. The right leg and left arm advance together to make one step, and so of the left leg and right arm. When the right leg advances the right arm retires, and *vice versâ*. When the left leg advances the left arm retires, and the converse. There is therefore a complementary swinging of the limbs on each side of the body, the leg swinging always in an opposite direction to the arm on the same side. There is, moreover, a diagonal set of movements, also complementary in character ; the right leg and left arm advancing together to form one step ; the left leg and right arm advancing together to form the next. The diagonal movements beget a lateral twisting of the trunk and limbs at the shoulders and hips ; the oscillation of the trunk upon the limbs and feet, and the oscillation of the feet and limbs upon the trunk, generating a forward wave movement, accompanied by a certain amount of vertical undulation. The diagonal movements of the trunk and extremities are accompanied by a certain degree of lateral curvature ; the right leg and left arm, when they advance to make a step, each describing a curve the convexity of which is directed to the right and left respectively. Similar curves are described by the left leg and right arm in making the second or complementary step. When the curves formed by the right and left legs and the right and left arms are joined, they form waved figure-of-8 tracks symmetrically arranged on either side of a given line. The curves formed by the legs and arms intersect at every step. Similar curves are formed by the quadruped when walking, the fish when swimming, and the bird when flying.

From the foregoing it will be evident that the trunk and limbs have pendulum movements which are natural and peculiar to them, the extent of which depends upon the length of the parts. A tall man and a short man can consequently never walk in step if both walk naturally and according to inclination.[1]

In traversing a given distance in a given time, a tall man will take fewer steps than a short man, in the same way that a large wheel will make fewer revolutions in travelling over a given space than a smaller one. The relation is a purely mechanical one. The nave of the large wheel corresponds to the ilio-femoral articulation (hip-joint) of the tall man, the spokes to his legs, and portions of the rim to his feet. The nave, spokes, and rim of the small wheel have the same relation to the ilio-femoral articulation (hip-joint), legs, and feet of the small man. When a tall and short man walk together, if they keep step, and traverse the same distance in the same time, either the tall man must shorten and slow his steps, or the short man must lengthen and quicken his.

The slouching walk of the shepherd is more natural than that of the trained soldier. It can be kept up longer, and admits of greater speed. In the natural walk, as seen in rustics, the complementary movements are all evoked. In the artificial walk of the trained army man, the complementary movements are to a great extent suppressed. Art is consequently not an improvement on nature in the matter of walking. In walking, the centre of gravity is being constantly changed—a circumstance due to the different attitudes assumed by the different portions of the trunk and limbs at different periods of time. All parts of the trunk and limbs of a biped, and the same may be said of a quadruped, move when a change of locality is effected. The trunk of the biped and quadruped when walking are therefore in a similar condition to that of the body of the fish when swimming.

In running, all the movements described are exaggerated. Thus the steps are more rapid and the strides greater. In walking, a well-proportioned six-feet man can nearly cover his own height in two steps. In running, he can cover without difficulty a third more.

As the various movements witnessed in walking and running in man are primarily due to his muscular system, which is elaborate and powerful, it is necessary at this stage shortly to refer to it. I consequently give three views of the said system ; namely, an anterior, lateral, and posterior view, as seen in a well-developed adult male (Figs. 390, 391, and 392).

Without going into the subject too minutely, an attentive examination of the figures will reveal the important

[1] "The number of steps which a person can take in a given time in walking depends, first, on the length of the leg, which, governed by the laws of the pendulum, swings from behind forwards ; secondly, on the earlier or later interruption which the leg experiences in its arc of oscillation by being placed on the ground. The weight of the swinging leg and the velocity of the trunk serve to give the impulse by which the foot attains a position vertical to the head of the thigh-bone ; but as the latter, according to the laws of the pendulum, requires in the quickest walking a given time to attain that position, or *half* its entire curve of oscillation, it follows that every person has a certain measure for his steps, and a certain number of steps in a given time, which, in his natural gait in walking, he cannot exceed."

fact that, in all the regions of the body, the muscles are arranged in straight, slightly oblique, oblique, and transverse spiral lines ; a circumstance which accounts for the flexion or shortening and the extension or elongating of the limbs, for the curved spiral figure-of-8 pendulum movements of the limbs, for the double diagonal twisting which occurs at the shoulders and hips, for the ball-and-socket universal movements at the shoulders and hips, for the pronation, supination, and circumduction of the limbs, and for the spiral movements at the elbows and knees, at the wrists and ankles, and at the hands and feet.

Thus in Fig. 390 (anterior view) straight, slightly oblique, and oblique spiral muscles are seen in the arms and legs, transverse muscles occurring in the deeper parts ; similar muscles are seen in the trunk ; the transverse ones

Fig. 390. Fig. 391. Fig. 392.

Figs. 390, 391, and 392.—Anterior, lateral, and posterior views of the muscular system in man (after Leveillé).

being well marked on the left breast and round the left shoulder joint where the left arm is united to the body. In Fig. 391 (right lateral view) the straight and oblique muscles are seen in the limbs, and the very oblique and transverse muscles in the trunk ; the very oblique and transverse muscles being well marked at the left shoulder and right hip where the left arm and right leg are articulated to the body by ball-and-socket joints and where universal movements occur. In Fig. 392 (posterior view) the straight, slightly oblique, very oblique, and transverse muscles are all represented ; the straight muscles preponderating in the limbs, and the oblique and transverse ones in the shoulders, hips, and trunk. The arrangement of the tendons of the muscles in the vicinity of joints, and especially in the hands and feet, is important as showing how the hands and feet, and parts thereof, are moved. The movements of the feet are a *sine qua non* in locomotion.

The figures under consideration show very conclusively that the muscles act in groups and in masses, and that no movement, however simple, is traceable to the action of any one muscle. The movements of every part of the body, and especially of the limbs, are due to simultaneous, co-ordinated action occurring in several muscles ; the muscles in every instance acting harmoniously, in a given direction and to a given end. But for this circumstance, ordinary walking and running in man would be impossible. So much is this the case, that the muscles concerned

in walking and running must be specially trained to act together, and one has only to watch the futile efforts of a child when learning to walk and run to realise what a slow, difficult, and serious matter it is to train muscles at the beginning of life. What holds true of the legs holds true of the arms and every part of the body. The complicated, graceful, spiral figure-of-8 movements already alluded to, which have still to be considered in detail, are due to the muscular arrangements, and the training of muscles, as referred to above.

All the points referred to in the walking and running of man can readily be made out and verified by a careful examination of instantaneous photographs.

Before describing the photographs illustrating the normal movements in walking and running in man, it may be well to allude very briefly to the artificial or abnormal movements as witnessed in a nude child walking on its hands and knees in imitation of the horse, and to a nude woman walking on all fours in imitation of a giraffe, where the extremities of the one side advance together to make one step and those of the other side advance together to make a second step (Figs. 393, 394, 395, and 396).

At Fig. 393 (child) the right arm which is straight, and the left leg which is flexed, are being advanced in diagonal and opposite complemental curves (see darts) to make one step.

At Fig. 394 the left arm which is straight and the right leg which is flexed, are being advanced in diagonal

Fig. 393. Fig. 394.

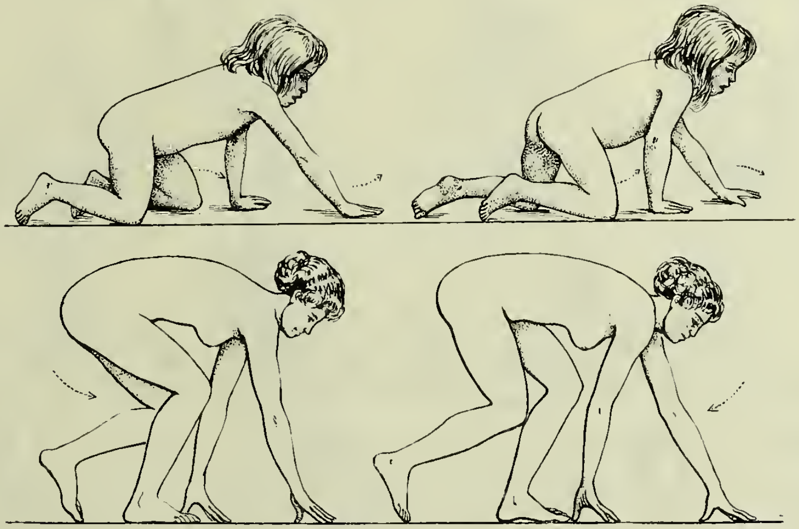


Fig. 395. Fig. 396.

Figs. 393 and 394.—Nude child walking on its hands and knees.
Figs. 395 and 396.—Nude woman walking on her hands and feet.

and opposite complemental curves (see darts) to make a second step. The screwing or twisting movements at the shoulders and hips are well seen in these figures.

At Fig. 395 (woman) the hips are seen screwing towards the spectator (*vide* curved dart); the shoulders screwing away from him.

At Fig. 396 the shoulders are seen screwing towards the spectator (*vide* curved darts); the hips screwing away from him. All these figures illustrate the diagonal-double-curve-screwing movements which occur at the shoulders and hips, and in the arms and legs respectively, both in artificial and natural walking.

The various positions assumed by the head, body, arms and hands, legs and feet, in the fast walk in a nude adult man are given at Figs. 397 to 404 inclusive.

At Fig. 397 the head and body are inclined forwards and the right arm and left leg are advancing together in diagonal opposite complemental curves (*see* curved darts *a*, *b*), to form one step; the left arm is swinging backwards (*see* curved dart *a′*) The toes of the right foot are on the ground and about to leave it in the direction indicated by the curved dart *b′*. The heel of the left foot is placed on the ground and the foot is about to roll forward in the direction indicated by the curved dart (*b*). This figure shows the heel and toe movement of walking to perfection.

At Fig. 398 the body is bent forwards and the head a little lower than in Fig. 397. The right arm and left leg are still in advance of the body, but the right and left arms are oscillating, pendulum-fashion, in opposite directions (*see* curved darts *c*, *c′*), the right foot has left the ground and is about to swing forward and describe

a curve whose convexity is directed away from the mesial line of the body (*see* curved dart *d′*). The left foot is rolling downwards and forwards on the heel (*see* curved dart *d*).

At Fig. 399 the body is less bent forward and the head a little higher than in Fig. 398. The body is beginning to roll over the left foot, which is firmly placed on the ground. The rolling movement is continued in Figs. 400, 401, 402, and 403. The right arm and left leg are still in advance of the body, the oscillations of the right and left arms in opposite directions being continued. The right and left arms are also nearing the body (*see* curved darts *e*, *e′*). The left foot is now placed on the ground, the right foot having still further left the ground (*see* curved darts *f*, *f′*).

At Fig. 400 the body and head are more erect than in Figs. 397, 398, and 399. The right arm (*g*) and left leg

Fig. 397. Fig. 398. Fig. 399. Fig. 400.

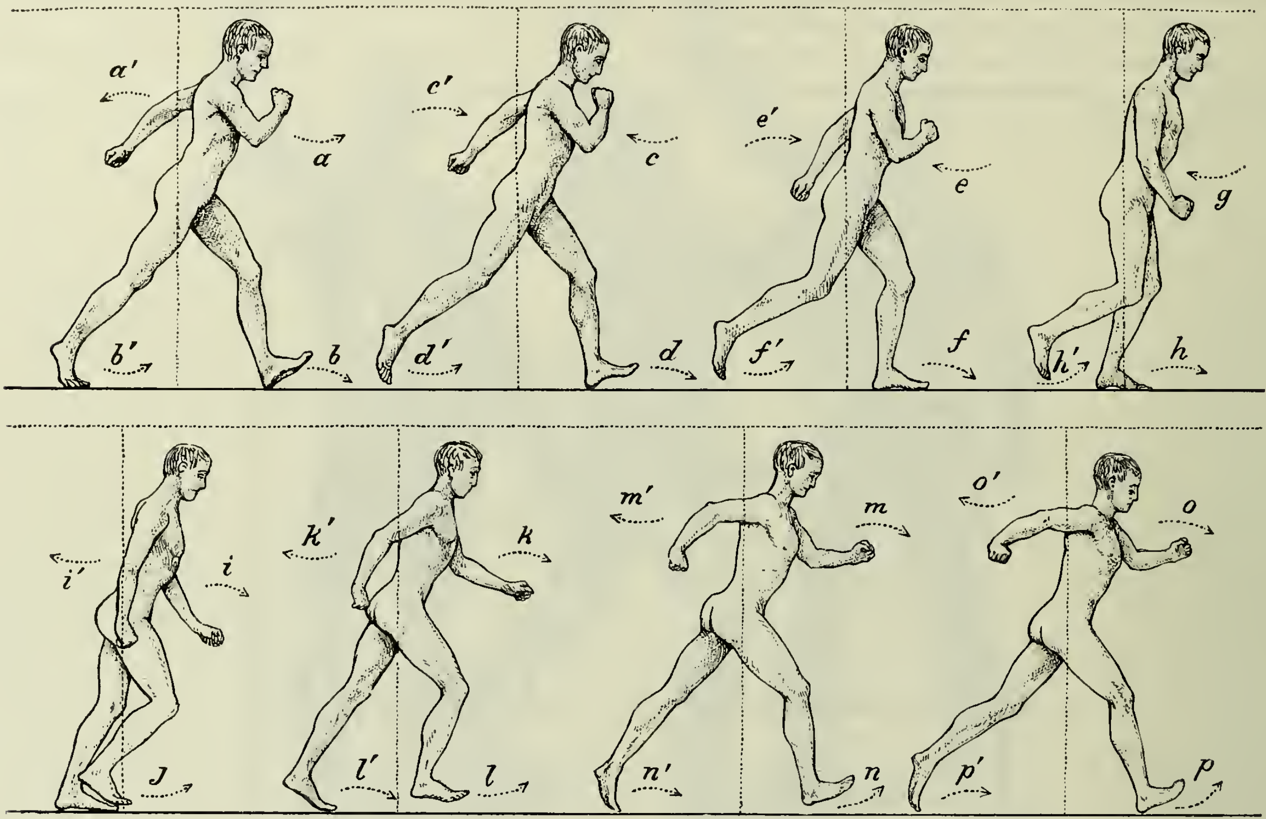


Fig. 401. Fig. 402. Fig. 403. Fig. 404.

Figs. 397 to 404.—A nude man walking at a brisk pace. The heel and toe movements and the forward roll of the feet, as well as the alternate forward roll of the trunk on the feet and legs, and of the feet and legs on the trunk, are well seen in these figures. The double and opposite diagonal screwing movements of the body at the shoulders and haunches in walking are seen to advantage at Fig. 403. In this figure the left arm (*m*) is screwing towards the spectator—the right leg (*n*) screwing away from him.

(*h*) are nearly in a line with the body; the right leg and foot being much more flexed and ready to swing forwards, pendulum-fashion, in the direction indicated by the curved dart *h′* to inaugurate a second step.

At Fig. 401 the body and head are a little more inclined forwards than in Fig. 400. The first step is completed, and the left arm and right leg are advancing together to begin a second step (*see* curved darts *i* and *j*). The right arm is beginning to swing back and the left foot is placed firmly on the ground.

At Fig. 402 the body and head are more inclined forwards than in Fig. 401. The left arm and right leg are in advance of the body and making diagonal opposite complementary curves (*see* curved darts *k*, *l*). The left and right arms are swinging in opposite directions (*see* curved darts *k*, *k′*); the right foot is off the ground and swinging forward (*see* curved dart *l*); the toes of the left foot (*l′*) only being on the ground.

At Fig. 403 the body and head are more bent forward than in Fig. 402. The left arm and right leg are well in advance of the body and making diagonal and opposite complemental curves (*see* curved darts *m*, *n*). The left and right arms are swinging pendulum-fashion in opposite directions (*m*, *m′*); the heel of the right foot (*n*) is about to be placed on the ground and the toe of the left foot (*n′*) is preparing to leave the ground. This figure shows in a striking manner the diagonal, screwing movements which occur at the shoulders and hips; the shoulders

twisting towards the spectator, and the hips away from him. It also shows how the arms and legs, oscillating as they do on either side of a given line, balance the body in the movements of walking. The oscillating arms and legs also help each other over their respective dead points, and so contribute powerfully to continuity of movement in the body as a whole.

At Fig. 404 the body and head are still more bent forward than in Fig. 403. The second step is completed, and the body and limbs are in the same position as in Fig. 397, with the difference that everything is reversed. Thus the left arm and right leg are in advance of the body and making diagonal opposite complemental curves (*see* curved darts *o*, *p*); the right arm and left leg being behind the body; the left and right arms are oscillating in opposite directions (*see* curved darts *o*, *o′*), but their positions are reversed when compared with their position in Fig. 397. Fig. 404 is in reality Fig. 397 reversed. Figs. 397 and 404, and 398 and 403 show in a characteristic manner the diagonal, screwing, figure-of-8 movements occurring at the shoulders and hips, which are so important in the continuous forward movements of the body as a whole; but all the other figures, namely, 399 and 402, and 400 and 401, show the same thing although in a lesser degree.

These movements are also seen to advantage in Figs. 405 to 410 inclusive, which represent a man walking rapidly as observed from before and from behind.

In Fig. 405 (anterior view) the pedestrian is making a step with the right leg and foot; the left arm (*a*) and

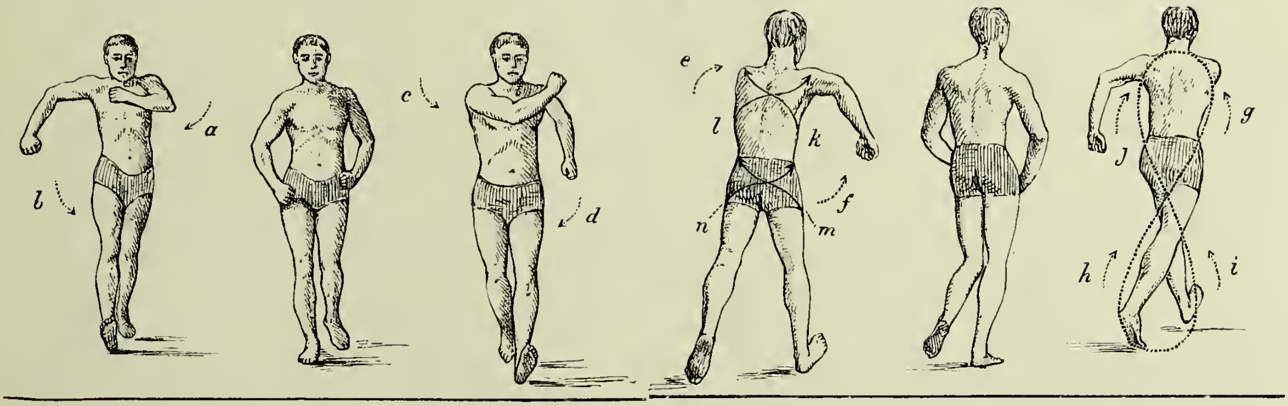


FIG. 405. FIG. 406. FIG. 407. FIG. 408. FIG. 409. FIG. 410.

FIGS. 405 TO 410.—Show the curved, diagonal, screwing, figure-of-8 movements made by a man in walking, anterior and posterior views.

right leg (*b*) advancing and forming diagonal and opposite complemental curves (*see* curved darts *a*, *b*). These movements are largely occasioned by a diagonal screwing or twisting at the left shoulder and right hip. In Fig. 407 (anterior view) a step is being made with the left leg and foot; the right arm (*c*) and the left leg (*d*) advancing and making diagonal and opposite complemental curves (*see* curved darts *c*, *d*), owing to a diagonal screwing or twisting occurring at the right shoulder and left hip.

In Fig. 406 (anterior view) a step by the left leg and foot is in progress. In this case the left shoulder is raised and the left leg and foot flexed and shortened and in the act of swinging forward pendulum-fashion. The raising of the shoulder always accompanies the flexion of the limb on the same side of the body. Thus when the right limb is flexed and making a step, the right shoulder is elevated; conversely when the left limb is flexed and making a step, the left shoulder is elevated. Fig. 407 is the reverse of Fig. 405.

In Fig. 408 (posterior view) the left arm (*e*) and right leg (*f*) are screwing forward and making diagonal and opposite complemental curves (*see* curved darts *e*, *f*); the heel of the right foot being placed on the ground, and the toes of the left foot being about to leave it. At *k*, *l*, the diagonal-screwing movements (*see* spiral, double-curved darts) occurring at the shoulders are represented, and at *m*, *n*, similar movements occurring at the hips are given. The spiral, double-curved darts cross each other from the fact that in walking the shoulders and hips twist alternately from right to left and from left to right; the rule being that the shoulders twist from right to left and the hips from left to right when the right leg leads and is making a step; while the shoulders twist from left to right and the hips from right to left when the left leg leads and is making a step. Each step is characterised by twisting, diagonal, spiral movements which are opposite and complemental at the shoulders and hips respectively. When the right leg and left arm advance together to make one step, as seen at Fig. 408, a spiral wave of movement runs as indicated by the double-curved darts in the direction *n*, *k*, *e*, of Fig. 408; conversely, when the left leg and right arm advance together to make a second step, a spiral wave of movement runs in an opposite direction, as indicated by the double curved darts *m*, *l*, of Fig. 408.

Seeing that the diagonal, spiral movements made by the trunk and limbs in walking and running cross each other, a more or less perfect figure-of-8 is developed, as seen at *h*, *g*, and *i*, *j*, of Fig. 410. As already explained, a similar trajectory is described on the ground by the complemental, opposite curves made by the right arm and left leg, and by the left arm and right leg which move diagonally in pairs.

In Figs. 406 and 409 the right leg is extended and the right foot is placed on the ground; the left leg and foot being flexed and in the act of swinging forward with the right arm. The left shoulder is raised.

Having now discussed the various complementary, curved, figure-of-8 pendulum-movements which take place in the arms and legs, and the diagonal, screwing movements which occur at the shoulders and hips in rapid walking in man, we are in a position to deal with the comparatively rapid and powerful movements witnessed in running.

In the run in the adult male, the movements described in the walk are repeated and exaggerated. The body

Fig. 411. Fig. 412. Fig. 413. Fig. 414.

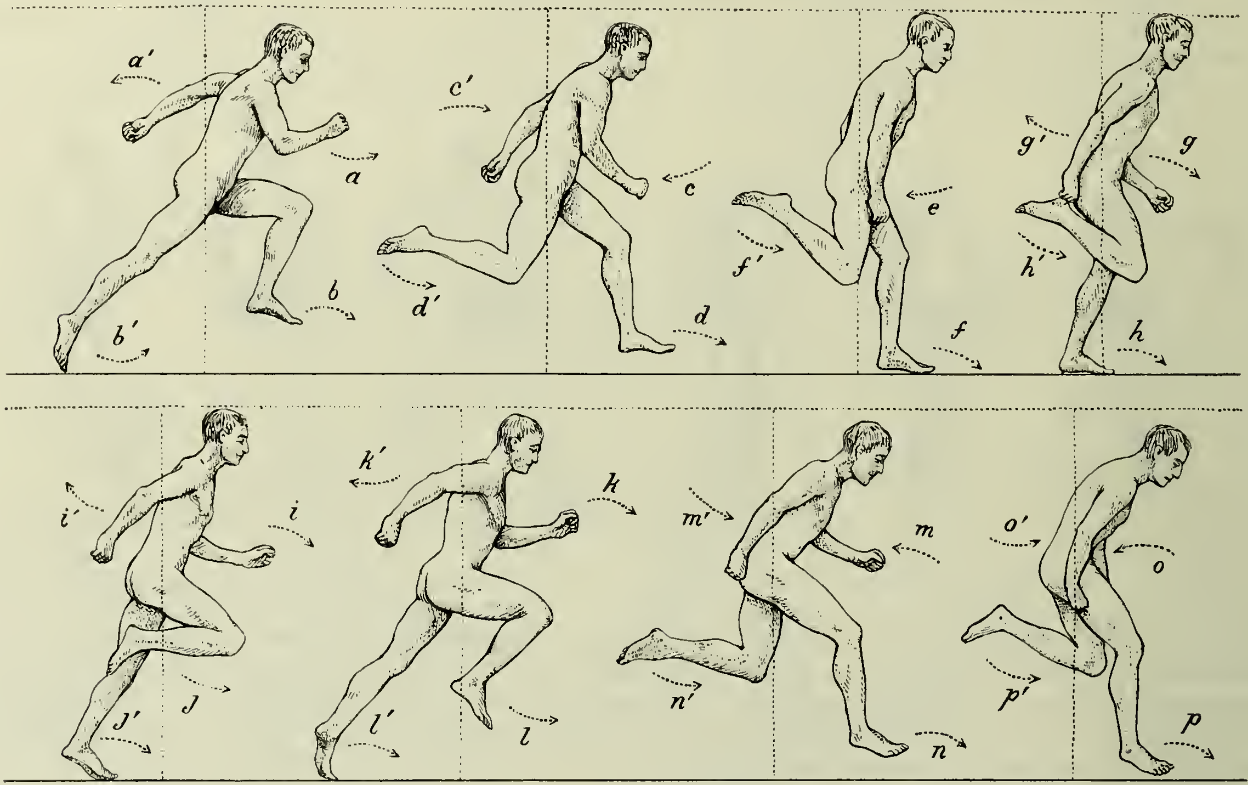


Fig. 415. Fig. 416. Fig. 417. Fig. 418.

Figs. 411 to 418.—A nude man running.

is bent more forward and the head lowered; the arms and legs are more vigorously flexed and extended and more widely separated, and a period occurs in each step when the feet are entirely off the ground. The speed and momentum acquired by the body are also greatly increased. These points are illustrated by Figs. 411 to 418 inclusive.

In Fig. 411, the body is bent much forward and the head lowered considerably below the horizontal line. The right arm (*a*) and left leg (*b*) are swinging forward in space pendulum-fashion to make diagonal and opposite complemental curves. The arms and the legs are widely separated, the amount of diagonal screwing and twisting occurring at the shoulders and hips having reached a maximum. The arms (*a*, *a′*) are swinging pendulum-fashion in opposite directions. The toes of the right foot (*b′*) are leaving the ground, and the left foot is high in air. The whole body is undergoing great exertion and is in a condition of physical tension and strain.

In Fig. 412 the right arm (*c*) and the left leg (*d*) are in advance of the body and making diagonal and opposite complemental curves; the oscillating, pendulum movements of the arms (*c*, *c′*) are reversed and the arms less widely separated. The legs (*d*, *d′*), on the contrary, are more widely separated, and, what is important, both feet are off the ground.

In Fig. 413 the body is more erect than in Figs. 411 and 412, and the head elevated and nearly touching the

top horizontal line. The right arm (e) and left leg (f) are nearly parallel with the body; the left leg is nearly straight and the left foot (f) is being placed on the ground; the right leg (f'), on the contrary, is much flexed and high in air, and in the act of swinging forward pendulum-fashion (*see* curved darts f').

In Fig. 414, the body is still more erect; the head touching the top horizontal line. The right arm (g) and left leg (h) are parallel with the body; the foot of the left leg which is straight being firmly planted on the ground. The right leg (h'), on the other hand, is flexed to its utmost and in the act of swinging forward pendulum-fashion to begin a new step. The arms and legs in this figure are less separated than in any of the other figures. As a matter of fact, one step is completed and the body is gathering itself together to make a second step. The arms (g, g'), it will be observed, are reversing their oscillating, pendulum movements (*see* curved darts). The head and body are now in a position to roll forward on the left leg and foot (h).

At Fig. 415 a new step is commenced, and the body is slightly inclined forwards and beginning to roll over on the left foot (j'). The arms and legs are beginning to separate. The left leg is fully extended, and the right leg nearly fully flexed and swinging forward (j) pendulum-fashion. (Compare the position of this, the right leg, with that of the same leg in Fig. 414.) The right leg and left arm are in advance of the body and making diagonal and opposite complemental curves (*see* curved darts i, j). The right and left arms (i, i') are swinging in opposite directions.

In Fig. 416, the movements recorded in Fig. 415 are exaggerated. The body is bending more forward, the head is slightly lowered, and the arms (k, k') and legs (l, l') are more separated.

In Fig. 417, the body is more bent forward and the head lower than in Fig. 416. There are notable changes also in the arms and legs. Thus the arms (m, m') have reversed their oscillating, pendulum movements, and are less widely separated, while the legs (n, n') are much more widely separated and flexed, especially the left one (n'), and the feet of both legs are off the ground.

In Fig. 418, the body is much bent forward and the head lowered, the arms (o, o') are nearly parallel with the body and about to reverse their oscillating, pendulum movements; the right leg (p) is nearly fully extended, and the right foot is in the act of being placed on the ground; the left leg (p'), on the contrary, is much flexed and in the act of swinging forward to begin, in conjunction with the right foot, a new step.

Before leaving the subject of locomotion in man, it is necessary to reiterate that not only do the legs and arms form diagonal complementary curves, but the legs themselves tend to plait and overlap. The plaiting of the limbs is best seen in the female form; the greater breadth of the pelvis conferring on the woman an increased degree of curved movements.

§ 345. Locomotion of the Horse.

The movements of this superb animal require more than a passing notice, and are described in detail further on. The existence of this noble animal is now threatened by the automobile, which is increasing in popularity so rapidly as to point to a possible extinction of this quadruped at no very distant day. The horse has a history and a pedigree to which no other animal can lay claim. It is the handsomest of all the quadrupeds, and has a grace and stateliness all its own. It has been the companion of man from the earliest times and in all countries. Its strength and endurance, its docility and courage, have made it equally valuable in peace and war. It lends itself readily to display and pomp, and is valuable in the field alike for sport and toil. All its actions reveal power, agility, and adaptability. Its several paces, with which we are more especially concerned, have been admired and studied by all nations, and endless discussions have arisen thereupon. But for the timely discovery of instantaneous photography, it would have been impossible to determine with perfect accuracy the innumerable knotty points which beset this complicated subject. As, however, the legs and feet of the horse, in all possible positions, have been photographed, and the photographs reproduced in permanent and available form, the mastery of the subject is a mere question of detail and patience.

THE OSSEOUS SYSTEM OF THE HORSE

Before analysing the order and sequence of the movements which result in flexing the limbs and lifting the feet off the ground, and in extending the limbs and placing the feet on the ground, it may be well to refer briefly to the skeleton of the horse as seen in walking, trotting, and galloping, as the skeleton displays, so to speak, the inner and passive mechanism by the aid of which the several movements are produced. It will be well also to direct attention to the muscular system of the horse; the muscles furnishing the motive power which sets the

Fig. 419.—Fine example of an entire Clydesdale horse, especially drawn for the Author of the present work by C. Berjeau from a selected photograph.

bones of the extremities in motion. A consideration of the skeleton and of the muscular system of the horse reveals the source of its activity and power.

The bones of the extremities of the horse, and of all quadrupeds, form levers, and these levers are inclined towards each other at various degrees of obliquity, and, in conjunction with the joints, form greater or lesser angles. If the bones make small angles with each other, the speed attained by the limbs and the animal, as a rule, is high; if they make large angles the speed, for the most part, is slow or moderate.

In the horse and in all fleet animals the angles formed by the bones with each other are small, and this remark applies not only to the bones of the extremities themselves but also to the angles made by the arm bones with the scapulæ, and by the thigh bones with the pelvic bones. In the deer (Fig. 344, p. 1093) the angles made by the bones of the extremities are smaller than in the horse (Fig. 421)—the speed being greater. In the ostrich again, the angles are less than in the deer; the ostrich being the fleeter of the two. In the wings of birds, the angles are less than in either the ostrich, deer, or horse; flight being more rapid than any form of terrestrial progression.

In the elephant the angles are large; the legs being perpendicular and nearly straight, as this is the best arrangement for supporting superincumbent weight.

The high speed of the elephant is less due to the angles made by its limbs than to its enormous size and great stride.

In man the angles are also great; the limbs, as in the elephant, being nearly straight. This arrangement is necessary for vertical support. As a consequence, the speed attained by man in walking and running is comparatively slow.

The forms of the bones, and the angles made by them in locomotion, reveal mechanical adaptations to neutralise shock, to increase elasticity, and to secure velocity.

Figs. 421, 422, and 423 supply the necessary illustration.

FIG. 420.—Typical example of an English race-horse, especially drawn for the Author of the present work by C. Berjeau from a selected photograph.

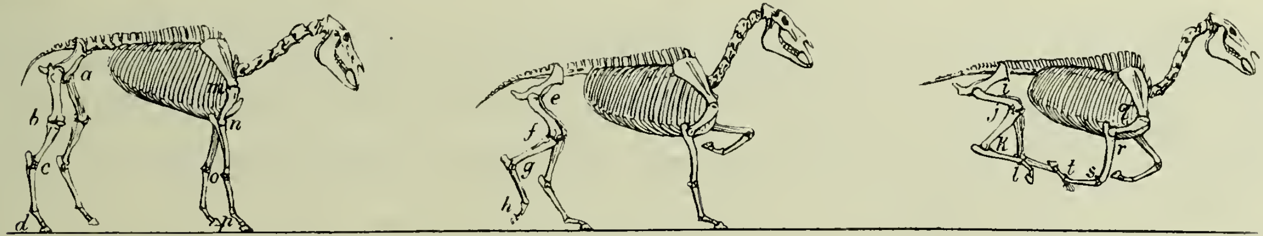


FIG. 421. FIG. 422. FIG. 423.

FIGS. 421, 422, AND 423.—Skeleton of a horse with the bones placed in the positions occupied by them in walking, trotting, and galloping. These figures show that the angles made by the bones of the extremities are less in galloping than in trotting, and in trotting than in walking.

The angles made by the bones of the hind legs in walking are seen in Fig. 421. *a*, Angle made by the femur with the pelvis; *b*, angle made by the tibia with the femur; *c*, angles made by the metatarsus with the tibia; *d*, angle made by the phalanges with the metatarsus. These angles are comparatively large or obtuse.

The angles as seen in the trot are given at *e, f, g, h*, of Fig. 422. They are smaller or more acute than in Fig. 421, the trot being a more rapid movement than the walk. They are still smaller in the gallop, as seen at *i, j, k, l*, of Fig. 423; the gallop being the fastest pace of the horse. In the gallop all the extremities are violently flexed, the angles made by the several bones being the smallest possible. The angles made by the forelegs are seen at *q, r, s, t*, of Fig. 423.

The angles made by the bones of the limbs of animals in locomotion are determined by the amount of extension and flexion in the limbs themselves; the angles being large when the limbs are extended or nearly straight, and small when the limbs are flexed and bent. In the former case the limbs are elongated; in the latter case they are shortened. This important point is well illustrated by the so-called lazy tongs.

When the handles of the tongs are separated the angles formed by their component parts are reduced and the tongs shortened (Fig. 389, A). When the handles are drawn together the angles referred to are increased and the tongs lengthened (Fig. 389, B). Precisely the same thing occurs in the flexion and shortening and in the extension and elongating of the limbs in locomotion.

The muscles which move the bones of the horse are given at Fig. 424.

THE MUSCULAR SYSTEM OF THE HORSE

The horse, as stated, is famous for the rapidity and grace of its movements, and its muscles, as was to be expected, are numerous, complicated, and arranged on fine lines. They are disposed, for the most part, spirally in straight, slightly oblique, oblique, and transverse groups, also in fan-shaped sets symmetrically on either side of the body (Fig. 424).

The muscles of the head are chiefly connected with the movements of the ears, eyes, nostrils, mouth, jaws, and tongue; those of the neck with the movements of the head and neck; those of the shoulders with the diagonal, twisting, plaiting movements of the fore limbs; those of the trunk with the movements of the thorax and abdomen, plus the diagonal movements peculiar to locomotion, and those of the buttocks with the diagonal, twisting, screwing movements of the hind limbs. The shoulder, buttock, and leg muscles are more especially concerned in locomotion. If the muscles of the shoulder and fore limb of the left side be examined in a direction from above downwards (*vide* Fig. 424), they will be seen to follow a straight, oblique, plicated, and spiral arrangement; the oblique, spiral plication corresponding with the articulation of the left humerus and the upper part of the left foreleg with the left scapula and trunk, where spiral, curved, and semi-rotatory movements occur; the straight muscles being found, more especially, on the upper part of the left foreleg where they effect the important movements of extension and flexion. If the muscles of the left buttock and left hind limb be examined they will be seen to follow a similar arrangement to that described in the left shoulder and left fore limb; the plication and spirality being, on the whole, more marked, as was natural, considering the more perfect ball-and-socket joint formed by the left side of the pelvis with the head of the left femur. The universal joints by which the fore and hind limbs are united to the trunk of the horse, and the oblique, plicated, spiral arrangement of the muscles investing the universal joints, explain how the alternating, diagonal, complemental, and opposite movements and curves made by the anterior and posterior limbs in walking, running, and galloping are produced; the movements and curves when they run into each other giving rise to continuous figure-of-8 movements and curves first described by me in 1867, and more fully in 1873.

The distribution of the oblique spiral muscles on the shoulder and hip joints occasions an unmistakable screwing, spiral movement of the shoulders and hips in locomotion; the screwing movement at the shoulders being from right to left when it is from left to right in the hips, and *vice versâ*. The screwing movements in the shoulders and hips are diagonal in character, that is, they have an oblique crossed action; and this action corresponds with the lateral and diagonal supports provided by the feet of the horse in its several paces; the horse when in motion alternately rolling from side to side and more or less diagonally.

The horse has also an antero-posterior action, when the body is supported alternately on two fore or two hind feet, or on anterior or posterior tripods formed by three feet. The body of the horse when in action is supported in four different ways: (*a*) on one foot; (*b*) on two feet, namely, the two anterior or two posterior feet; the two feet of the right or left sides; the two feet placed diagonally to right or left; (*c*) on three feet; the feet forming alternating anterior and posterior right and left tripods; and (*d*) on four feet, as happens at intervals when the animal is walking very slowly.

As some confusion has arisen as to what is meant by a step and a stride in animal mechanics, it may be well to explain the points of difference.

By a step is meant the lifting of a foot from its position of rest and the carrying of it forward to a new position in advance of that originally occupied by it; the space covered by the step varying according to circumstances, and being always considerably less in slow walking than in quick walking and in running.

By a stride is meant the lifting, advancing, and replacing of two or more feet on the ground in succession; the stride being completed when the foot first lifted and those which followed in sequence have returned to their original positions of rest. Thus the stride of a man or a bird consists of two steps, while the stride of a quadruped consists of four steps.

The stride, like the step, varies greatly according as the animal is progressing at a low or a high rate of speed.

The amount of ground covered by the step and the stride respectively varies in different animals, and according to the degree of speed at which they are travelling. Thus in the horse in walking, the stride is usually a little over five feet, in the trot ten feet or thereby, and in the gallop something like eighteen feet.

The speed, as explained by Mr. Gamgee,[1] determines the length of the stride; the length of stride being the

[1] *Journal of Anatomy and Physiology*, vol. iii. p. 375.

effect and evidence of speed and not the cause of it. In the Newfoundland dog the stride is a little over nine feet, whereas in the greyhound and hare it is sixteen feet.

In the step and stride the body of the horse moves in advance of the feet. This is well seen when the horse is beginning its slowest action, as in traction.

The paces of the horse are seven in number, namely, the walk, trot, gallop, canter, amble, rack, and ricochet.

The three fundamental paces are the walk, the trot, and the gallop ; the others being artificial and due to training.

If the horse begins his walk by raising his near fore foot, the order in which the feet are lifted is as follows :

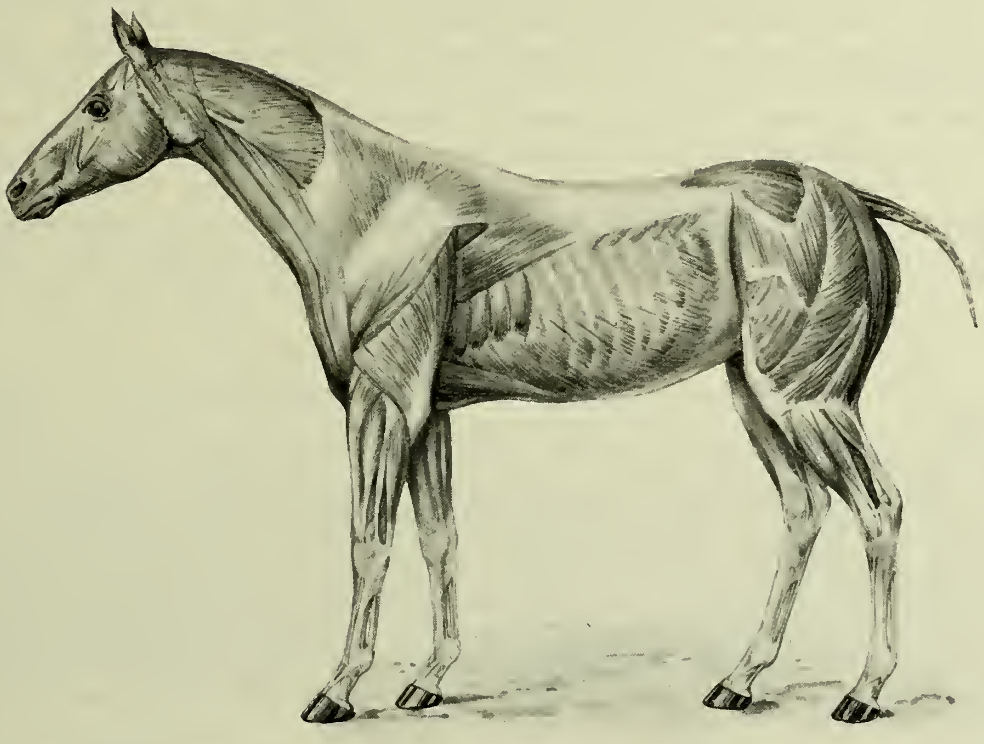


FIG. 424.—Muscles of the horse. Shows the plicated spiral arrangements of the muscles, more especially at the shoulder and hips, where curved, semi-rotatory spiral movements occur in walking, trotting, and galloping. The nearly straight muscles are seen in the legs, where they produce the important movements of flexion and extension. The muscles of the horse, as a whole, are arranged in straight lines, slightly obliquely, obliquely, and transversely, and, with few exceptions, reveal a spiral trend. In order to realise this description the deeper muscles must also be exposed and seen. The muscles are, for the most part, disposed in groups and sets, and cross or tend to cross each other at various degrees of obliquity ; an arrangement which secures the greatest possible strength with the least possible material, and ensures symmetry and perfect accuracy of movement in the various regions of the body (after Lupton : the general arrangements of the muscles, and the movements of the muscles and bones, analysed and described by the Author, 1873).

first the left fore foot, then the right or diagonal hind foot, then the right fore foot, and lastly the left or diagonal hind foot. There is therefore a twisting of the body and spiral overlapping of the extremities of the horse in the act of walking, in all respects analogous to what occurs in other quadrupeds [1] and in bipeds. In the slowest walk Mr. Gamgee observes " that three feet are in constant action on the ground, whereas in the free walk in which the hind foot passes the position from which the parallel fore foot moves, there is a fraction of time when only two feet are upon the ground, but the interval is too short for the eye to measure it. The proportion of time, therefore, during which the feet act upon the ground, to that occupied in their removal to new positions, is as three to one in the slow, and a fraction less in the fast walk. In the fast gallop these proportions are as five to three. In all the paces the power of the horse is being exerted mainly upon a fore and hind limb, with *the feet implanted in diagonal positions.* There is also a constant parallel line of positions kept up by a fore and hind foot, *alternating sides* in each successive move. These relative positions are renewed and maintained. Thus each fore limb assumes, as it alights, the advanced position parallel with the hind just released and moving ; the hind

[1] If a cat when walking is seen from above, a continuous wave of movement is observed travelling along its spine from before backwards. This movement closely resembles the crawling of the serpent and the swimming of the eel.

feet move by turns, in sequence to their diagonal fore, and in priority to their parallel fellows, which following they maintain for nearly half their course, when the fore in its turn is raised and carried to its destined place, the hind alighting midway. All the feet passing over equal distances and keeping the same time, no interference of the one with the other occurs, and each successive hind foot as it is implanted forms a new diagonal with the opposite fore, the latter forming the front of the parallel in one instant, and one of the diagonal positions in the next: while in the case of the hind, they assume the diagonal on alighting and become the terminators of the parallel in the last part of their action."

In the trot, according to Bishop, the legs move in pairs diagonally. The same leg moves rather oftener during the same period in trotting than in walking, or as six to five. The velocity acquired by moving the legs in pairs, instead of consecutively, depends on the circumstance that in the trot each leg rests on the ground during a short interval, and swings during a long one; whilst in walking each leg swings a short, and rests a long period. The undulations arising from the projection of the trunk in the trot are chiefly in the vertical plane; in the walk they are more in the horizontal.

The gallop has been erroneously believed to consist of a series of bounds or leaps, the two hind legs being on the ground when the two fore legs are in the air, and *vice versâ*, there being a period when all four are in the

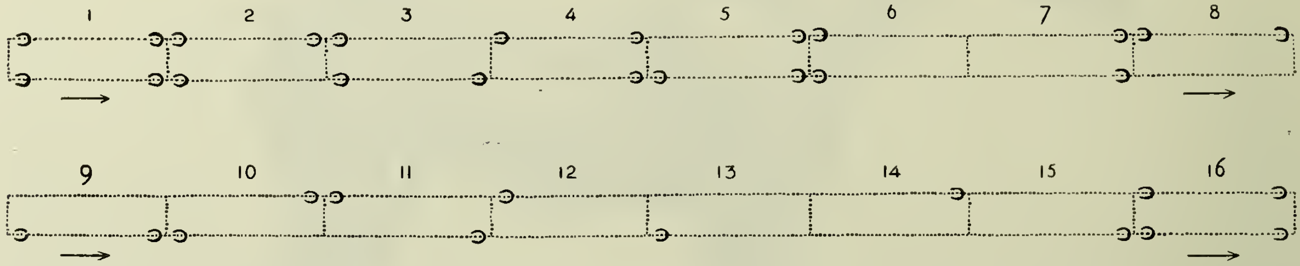


Fig. 425.—Indicates the different positions taken up by the feet of the horse in executing its several paces. At 1, the four feet are on the ground. At 2, the two hind feet and the left fore foot are on the ground and form a tripod of support (posterior left tripod). At 3, the two hind feet and the right fore foot are on the ground and form a similar but opposite tripod of support (posterior right tripod). At 4, the tripod of support is formed by the two fore feet and the left hind foot (anterior left tripod), and at 5, by the two fore and right hind foot (anterior right tripod). At 6, the body is supported on the two hind feet, and at 7, on the two fore feet. At 8, the body is supported on the fore and hind feet of the left side, and at 9, by the fore and hind feet of the right side. In these two positions (8 and 9) the body rolls from side to side. At 10, the body is supported diagonally by the right hind and left fore feet, and at 11, by the left hind and right fore feet. In these positions (10 and 11) the body twists and rolls diagonally. At 2, 3, 4, and 5, it is supported on antero-posterior tripods. At 12, the body is supported by the left hind foot, and at 13, by the right hind foot. At 14, the body is supported by the left fore foot, and at 15, by the right fore foot. At 16, the four feet are on the ground as at 1 (the Author).

air. Thus Sainbell, in his "Essay on the Proportions of Eclipse," states "that the gallop consists of a repetition of bounds, or leaps, more or less high, and more or less extended in proportion to the strength and lightness of the animal." A little reflection will show that this definition of the gallop cannot be the correct one. When a horse takes a ditch or fence, he gathers himself together, and by a vigorous effort (particularly of the hind legs), throws himself into the air. This movement requires immense exertion and is short-lived. It is not in the power of any horse to repeat these bounds for more than a few minutes, from which it follows that the gallop, which may be continued for considerable periods, must differ very materially from the leap.

The pace known as the amble is an artificial movement, produced by the cunning of the trainer. It resembles that of the giraffe, where the right fore and right hind foot move together to form one step; the left fore and left hind foot moving together to form the second step. By the rapid repetition of these movements the right and left sides of the body are advanced alternately by a lateral swinging motion, very comfortable for the rider, but anything but graceful. The amble is a defective pace, inasmuch as it interferes with the diagonal movements of the limbs, and impairs the continuity of motion which the twisting, cross movement begets. Similar remarks might be made of the gallop if it consisted (which it does not) of a series of bounds or leaps, as each bound would be succeeded by a halt, or dead point, that could not fail seriously to compromise continuous forward motion.

The limbs and feet in executing the seven paces referred to occupy no fewer than fifteen different positions, as the annexed figure shows (Fig. 425).

The walk, the trot, and the gallop are the most important paces of the horse, and require to be carefully described; the other paces, while interesting, do not demand the same degree of attention, and will be treated more briefly.

§ 346. The Walk of the Horse.

The movements made by the body and legs, and the positions assumed by the feet of the horse in walking, are numerous and at first sight complicated, but they can readily be analysed by the aid of instantaneous photography, which show the feet on the ground for the time being.

Leaving out of consideration for the present the order and sequence of the movements and supports, there are two sets of diagonal movements, when the animal is supported diagonally by the right hind and left fore feet, or

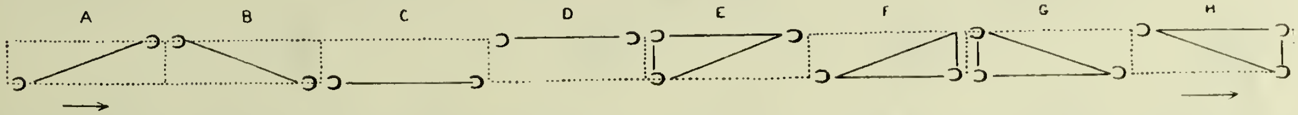


FIG. 426.—Gives scheme of positions which may be assumed by the feet of the horse in walking. At A and B, the supports supplied by the feet are diagonal; at C and D lateral; at E and F, and at G and H, antero-posterior, right and left tripods (the Author).

conversely by the left hind and right fore feet. Thus there are two lateral movements when the horse is supported laterally by the right fore and right hind feet, or conversely by the left fore and left hind feet; in addition there are four antero-posterior movements, when the horse is supported by anterior and posterior right and left tripods formed by the two hind and left fore feet; by the two fore and right hind feet; by the two hind and right fore feet; and by the two fore and left hind feet. At A and B of Fig. 426 it will be seen that the horse

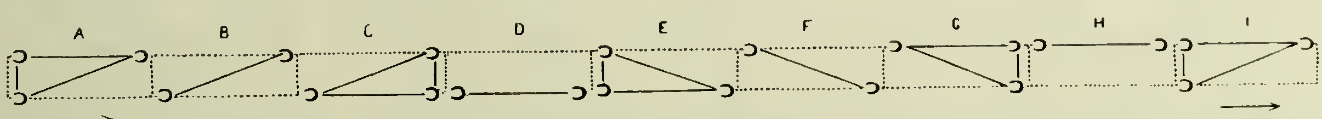


FIG. 427.—Chart of positions assumed by the feet of the horse in walking. At A, the feet provide a posterior tripod support (left). At B, a diagonal support. At C, an anterior tripod support (right). At D, a right lateral support. At E, a posterior tripod support (right). At F, a diagonal support (the opposite of that seen at B). At G, an anterior tripod support (left). At H, a left lateral support. At I, a posterior tripod support (left) as at A (the Author).

is supported diagonally and alternately by a left fore and right hind foot and by a right fore and left hind foot; that at C and D it is supported laterally, alternately by a right fore and right hind foot, and by a left fore and left hind foot; that at E and F it is supported on tripods alternately by the two hind feet and the left fore foot, and by the two fore feet and the right hind foot; while at G and H it is supported alternately on tripods formed by the two hind feet and the right fore foot, and by the two fore feet and the left hind foot. Thus in the walk

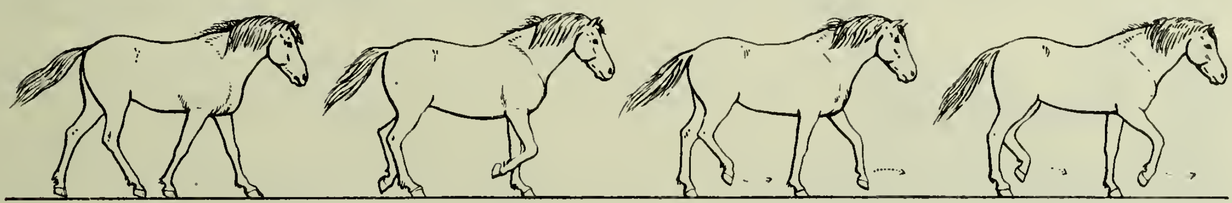


FIG. 428. FIG. 429. FIG. 430. FIG. 431.

FIGS. 428 TO 431.—Show some of the screwing and diagonal movements in the slow walk of the horse. At Fig. 428 the four feet are on the ground, the left foreleg having screwed and curved from left to right; the right hind leg having screwed and made a curve from right to left. At Fig. 429 the left fore foot and the right hind foot only are on the ground; the horse being supported diagonally. At Fig. 430, the right fore foot and the left hind foot only are on the ground, the horse being supported diagonally but on opposite feet to those seen at Fig. 429. At Fig. 431, the position of the feet is the same as that given at Fig. 429, the feet off the ground occupying, however, a more advanced position.

of the horse two diagonal movements, two lateral movements, and four antero-posterior tripod movements can be made out.

These various and apparently diametrically opposite movements all run into each other in the natural walk in the following order and sequence (Fig. 427).

In Fig. 427 it will be observed that the feet first provide a posterior tripod support (A), then a diagonal support (B), then an anterior tripod support (C), then a right lateral support (D), then a posterior tripod support (E), then a diagonal support (F), then an anterior tripod support (G), then a left lateral support (H), and finally, as at first, a posterior tripod support. There are thus four tripod supports to two diagonal and two lateral supports in each stride in walking. Examples of the several supports referred to are to be seen in a horse walking in Figs. 432 to 439 inclusive.

The movements required to produce the supports referred to involve a screwing motion at the shoulders and hips of the horse, and a plaiting of the anterior and posterior legs, well seen at Figs. 428, 429, 430, and 431.

The explanations given of the walking movements of the horse are readily confirmed by a reference to the following figures, which are accurate outline drawings of instantaneous photographs (Figs. 432 to 439).

FIG. 432.

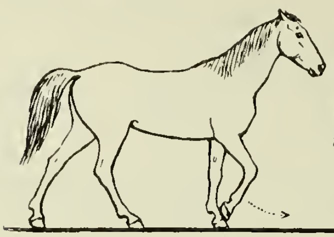


FIG. 433.

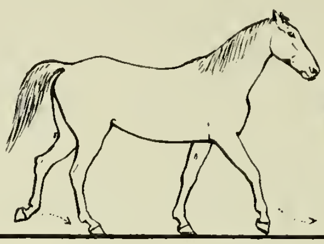


FIG. 434.

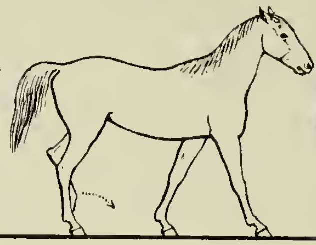
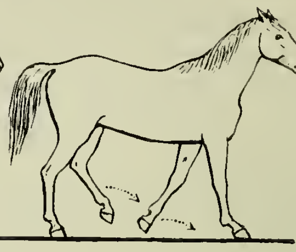


FIG. 435.



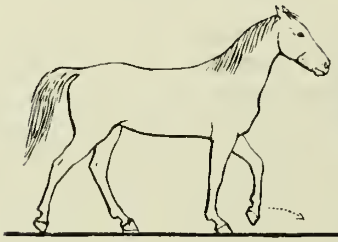


FIG. 436.

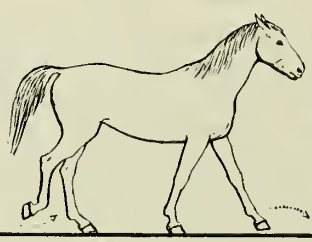


FIG. 437.

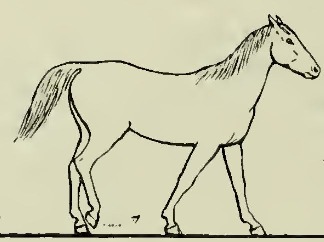


FIG. 438.

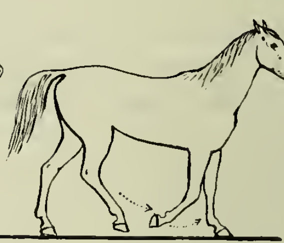


FIG. 439.

FIGS. 432 TO 439.—Give the positions of the legs and feet of the horse in the ordinary walk. The positions referred to are described in the text. The positions of the feet and legs in Fig. 432 are the reverse of those in Fig. 436, those in Fig. 433 of those in Fig. 437, those in Fig. 434 of those in Fig. 438, and those in Fig. 435 of those in Fig. 439.

The darts in the figures indicate the direction in which the legs and the feet move when off the ground. In Fig. 432, the two hind feet and the left fore foot are on the ground (posterior left tripod support). In Fig. 433, the left fore foot and the right hind foot are on the ground (diagonal support). In Fig. 434, the two fore feet and the right hind foot are on the ground (anterior right tripod support). In Fig. 435, the right fore foot and

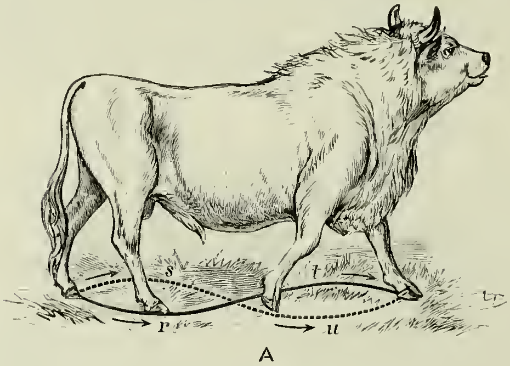


FIG. 440.

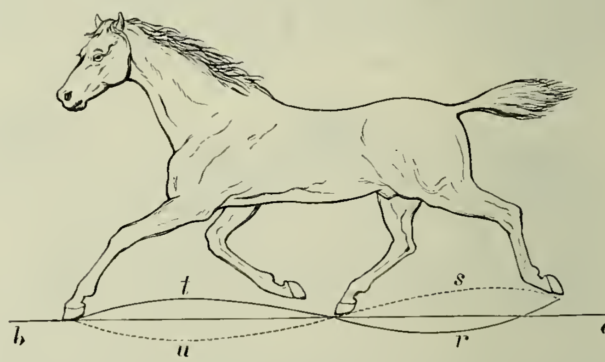


FIG. 441.

FIG. 440.—Shows the figure-of-8 trajectory made by the feet and limbs of the ox when walking. *s*, Curve made by the left hind leg and foot; *u*, curve made by the right fore leg and foot; *r*, curve made by the right hind leg and foot; *t*, curve made by the left fore leg and foot. The several curves when united produce the figure-of-8 trajectory.

FIG. 441.—Shows the figure-of-8 trajectory made by the feet and limbs of the horse when trotting. The lettering is the same as in Fig. 440; allowance, however, must be made for the reversal of the feet, as the horse and ox are represented as travelling in opposite directions (the Author, 1867, 1870, and 1873).[1]

the right hind foot are on the ground (right lateral support). In Fig. 436, the two hind feet and the right fore foot are on the ground (posterior right tripod support). In Fig. 437, the right fore foot and the left hind foot are on the ground (diagonal support). In Fig. 438, the two fore feet and the left hind foot are on the ground (anterior left tripod support). In Fig. 439, the left fore foot and the left hind foot are on the ground (left lateral support).

[1] "The Mechanical Appliances by which Flight is attained in the Animal Kingdom." (*Trans. Linn. Soc.*, vol. xxvi.)
"The Physiology of Wings." (*Trans. Roy. Soc. Edin.*, vol. xxvi.)
"Animal Locomotion." Anglo-American Science Series, 1873.

I have chosen to speak of the feet on the ground rather than the feet off the ground, as the feet on the ground plus the legs supply the support and leverage which enable the horse to walk. A study of the figures under observation shows how the feet are lifted from and placed on the ground ; curved darts always indicating the direction of the movements made by the feet and the limbs to which they are attached. The right fore leg and foot of the horse in walking describe a curve with its *convexity* directed towards the spectator ; the left hind leg and foot describing an opposite complemental curve with its *concavity* directed to the spectator. The left fore leg and foot describe a curve with its *concavity* directed to the spectator, and the right hind leg and foot describe an opposite complemental curve with its *convexity* directed towards the spectator. These four complemental curves when united form spirals which cross and so produce a true figure-of-8 trajectory (Figs. 440 and 441).

§ 347. The Trot of the Horse.

This pace, although considerably faster than the walk, is characterised by a greater simplicity in the arrangement of the supports furnished by the legs and feet. They are, as a rule, diagonal supports ; the body resting alternately on the right fore and left hind leg and foot, and on the left fore and right hind leg and foot. The several diagonal

Fig. 442. Fig. 443. Fig. 444. Fig. 445.

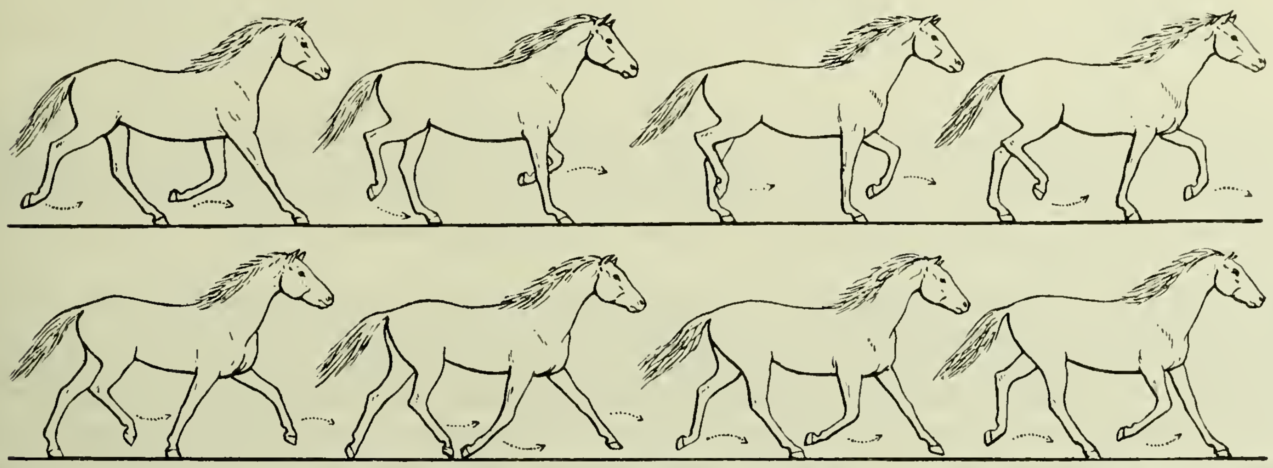


Fig. 446. Fig. 447. Fig. 448. Fig. 449.

Figs. 442 to 449.—These figures show the ever varying shapes and positions assumed by the body, legs, and feet of the horse in the slow trot. The curved darts indicate the direction of movement in the legs and feet.

positions, together with the transition movements made by the legs and feet when changing from the one diagonal to the other, as witnessed in the slow trot and recorded by instantaneous photography, are given at Figs. 442 to 449 inclusive.

At Figs. 442, 443, 444, 445, and 446, the diagonal supports provided by the right fore and left hind legs and feet are seen. In these figures the left fore and right hind legs and feet are flexed and in the act of swinging forwards, in curves (*see* curved darts). This they are free to do, as the complemental right fore and left hind legs and feet are firmly placed on the ground. At Fig. 442, the left fore and the right hind legs and feet are beginning to swing forward pendulum fashion. The pendulum forward movements are continued at Figs. 443, 444, 445, and 446. At Fig. 446, the left fore and right hind legs and feet are as far in advance of the right fore and left hind legs and feet as they were behind them in Fig. 442. At Figs. 447 and 448, the legs and feet are in the act of changing position in order to furnish new and opposite diagonal supports. The new diagonal supports are seen at Fig. 449, and it will be observed that this figure is the reverse of Fig. 442. Fig. 448 is also the reverse of Fig. 443 ; the other figures representing transitions. At Fig. 442 the diagonal supports are provided by the right fore and left hind legs and feet, whereas at Fig. 448 they are provided by the left fore and right hind legs and feet. In Fig. 442 there is a screwing of the left shoulder, left fore leg and foot towards the spectator ; the right hip, right hind leg and foot screwing in an opposite direction away from the spectator. At Fig. 449 these screwing movements are reversed ; the right shoulder and right fore leg and foot screwing away from the spectator, while the left hip and left hind leg and foot screw towards the spectator. The screwing movements referred to are necessary to a change and reversal of the diagonal supports. The horse in trotting, as in its other movements, rolls alternately on either side of a given line, and diagonally ; the diagonal movements preponderating. The anterior and posterior right and left tripods of support furnished by the limbs and feet are likewise diagonal in character.

In the fast trot there are periods when there is only one leg and foot on the ground, and when all the legs and feet are off the ground, as shown at Figs. 450, 451, 452, and 453.

The following chart of the footprints made by the feet of the horse in some phases of the fast trot may prove interesting (Fig. 454).

At A, the left hind foot only is on the ground. At B, the body is in the air. At C, the right fore foot only is on the ground. At D, there is a diagonal support, the right fore and the left hind feet being on the ground. At E, the left hind foot only is on the ground. At F, the body is once more in the air. At G, the left fore foot only is on the ground. At H, there is a second and opposite diagonal support caused by the left fore foot and

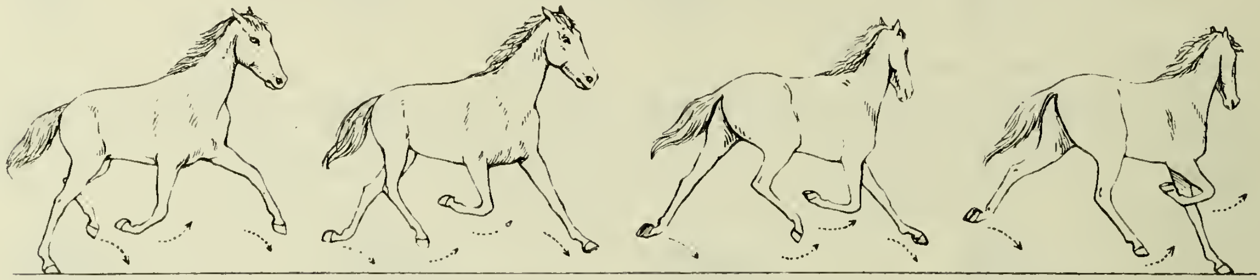


FIG. 450. FIG. 451. FIG. 452. FIG. 453.

FIGS. 450, 451, 452, 453.—Show the position of the legs and feet in certain phases of the rapid trot; the curved darts indicate the direction in which the legs and feet move. At Fig. 450, the body is supported entirely on the right hind leg and foot. At Fig. 453, it is supported entirely by the left foreleg and foot. At Figs. 451 and 452, the body is in the air. In Fig. 453, the legs and feet are in diametrically opposite positions to those occupied by them in Fig. 450. In Figs. 451 and 452, the limbs are altering their positions and shapes to admit of the transformation. The double screwing movement at the shoulders and hips is well seen in these figures. At Figs. 450 and 451, the chest is screwing towards the spectator; the hips away from him. In Figs. 452 and 453, the chest is screwing away from and the hips towards the spectator.

the right hind foot being on the ground. At I, the right hind foot is once more on the ground as at A. These movements are repeated with slight variations in rapid succession.

The old idea was that on no occasion did all the feet leave the ground in the trot. This view has, however, been shown to be erroneous by the aid of instantaneous photography in the case of celebrated trotting horses.

The diagonal positions assumed by the legs in the trot were well known to Mr. Bishop. According to him the legs move in pairs diagonally. The same leg moves rather more often during the same period in trotting than in walking, or as six to five. The velocity acquired by moving the legs in pairs, instead of consecutively, depends on the circumstance that in the trot each leg rests on the ground during a short interval, and swings during a long

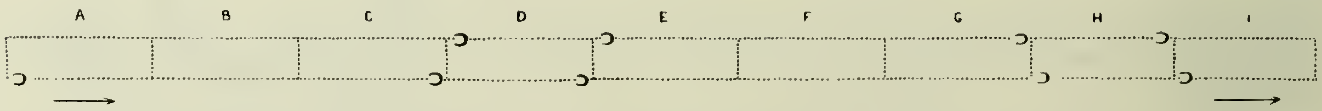


FIG. 454.—Chart of footprints of a horse in some phases of the fast trot (the Author).

one, whilst in walking each leg swings a short, and rests a long period. The undulations arising from the projection of the trunk in the trot are chiefly in the vertical plane; in the walk they are more in the horizontal.

§ 348. The Gallop of the Horse.

This is the swiftest of all the paces. A first-class English thoroughbred race-horse can do his mile in a little under two minutes. The limbs in the gallop make very energetic, rapid, and violent movements; the angles made by the several bones of the limbs being comparatively very acute.

The great speed attained by the horse in the gallop is due to three causes :—

(*a*) The great force exerted by the muscular system.

(*b*) The acute angles made by the bones of the limbs consequent on the violent action of the muscular cycles.

(*c*) The high momentum acquired by the body of the horse in rapid motion.

Each stride of a first-class race-horse occupies only the forty-fourth of a second and covers a distance of two hundred and seventy-four inches, or a mile in one hundred and two seconds or thereby.

The positions assumed by the limbs on and off the ground in the gallop may be represented as under (Figs. 455 and 456).

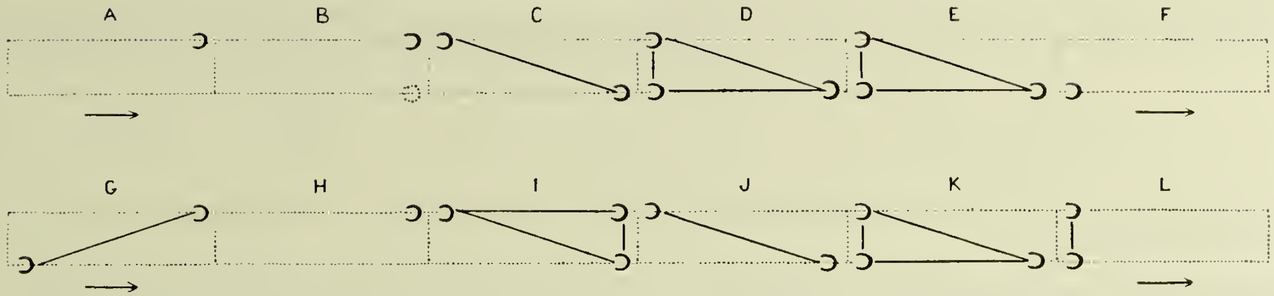


FIG. 455.—Chart of the footprints of a dray horse when galloping. At A, the body is supported by the left fore foot. At B, by the same foot, the right fore foot being near but not on the ground. At C, it is supported diagonally by the right fore and left hind feet. At D and E, by a posterior tripod composed of the right fore and the right and left hind feet. At F, by the right hind foot. At G, it is supported diagonally by the left fore and right hind feet; and at H, by the left fore foot alone. At I, by an anterior tripod composed of the two fore and left hind feet. At J, it is supported diagonally by the right fore and left hind feet. At K, by a posterior tripod consisting of the right fore and the right and left hind feet; and at L, by the two hind feet. It will be observed that in this chart while the body is on one foot four times, it is never wholly in the air. It is otherwise with the race-horse as seen at Fig. 456 (the Author).

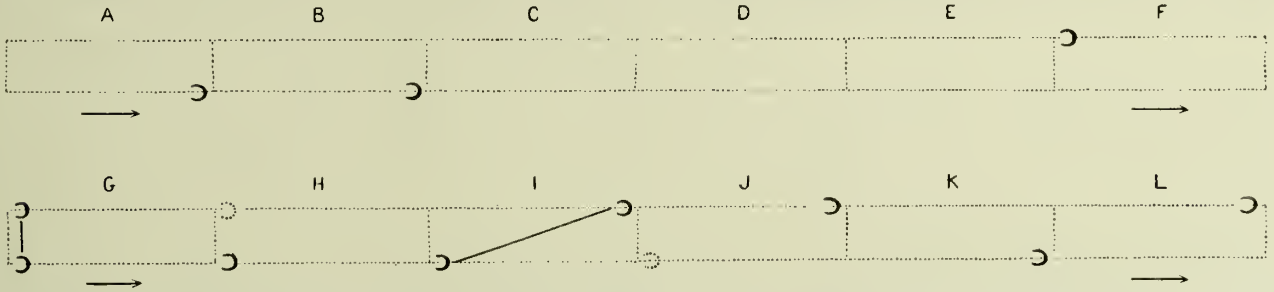


FIG. 456.—Chart of the footprints of a race-horse at full gallop. In this chart it will be observed that the body is frequently supported on only one foot and is in the air in three out of twelve phases. At A and B, the body is supported by the right fore foot only. At C, D, and E, it is off the ground altogether. At F, it is supported by the left hind foot only. At G, by the two hind feet. At H, by the right hind foot, the left one being near the ground. At I, it is supported diagonally by the left fore and right hind feet. At J, by the left fore foot, the right hind foot being near the ground. At K, by the right fore, and at L, by the left fore foot.

The difference in this chart, as compared with that given at Fig. 455, is traceable to the greater agility and lightness of the race-horse as compared with the dray horse (the Author).

The more important positions assumed by the legs and feet in the gallop may be studied to advantage in Figs. 457 to 464 inclusive.

FIG. 457. FIG. 458. FIG. 459. FIG. 460.

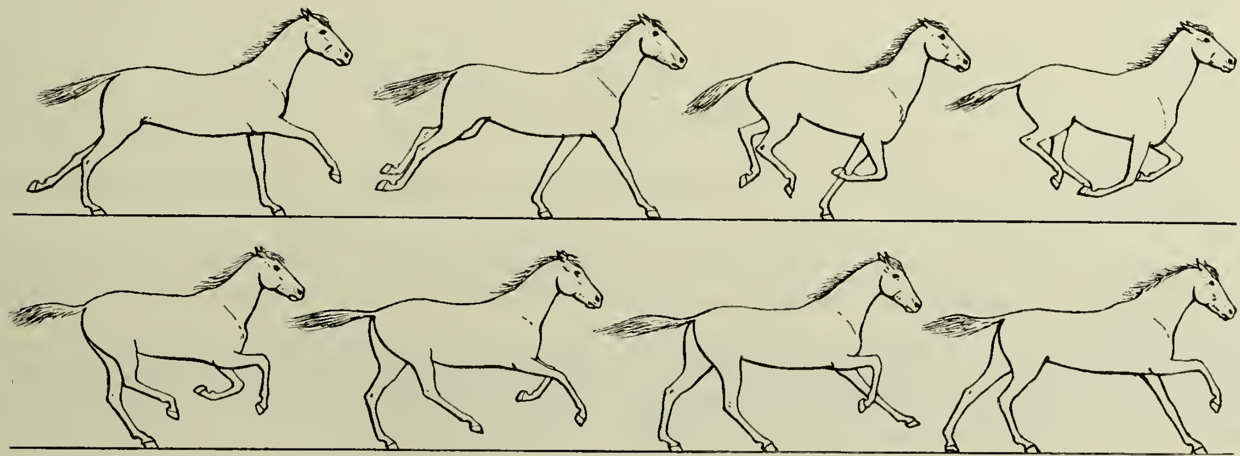


FIG. 461. FIG. 462. FIG. 463. FIG. 464.

FIGS. 457 TO 464.—Show positions assumed by the legs and feet of the horse in certain phases of the gallop.

At Fig. 457, the left fore and right hind foot are on the ground affording a diagonal support to the body of the horse. At Fig. 458, the two fore feet are on the ground supplying an anterior support At Fig. 459, the left fore foot is on the ground and the body rolling forwards. At Fig. 460, all the feet are off the ground, the body

experiencing next to no resistance to forward movement. At Fig. 461, the left hind foot is on the ground. At Fig. 462, the left hind foot is still on the ground. At Fig. 463, the right and left hind feet are on the ground :

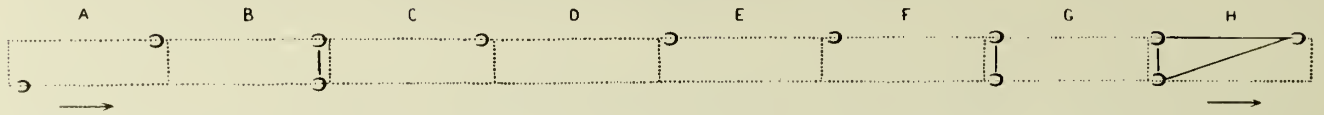


FIG. 465.—Chart of footprints made by the horse in the gallop. This chart resembles other charts already given and requires no explanation (the Author).

this figure is the reverse of Fig. 458. At Fig. 464, the left fore and the two hind feet are on the ground. A chart of the various foot supports as seen in the foregoing, Figs. 457 to 464 inclusive, is given at Fig. 465.

§ 349. The Canter of the Horse.

The canter, as its name indicates, is characterised by a bounding, hobbling movement in an antero-posterior direction with a certain amount of lateral oscillation, the antero-posterior movement being well marked. It is

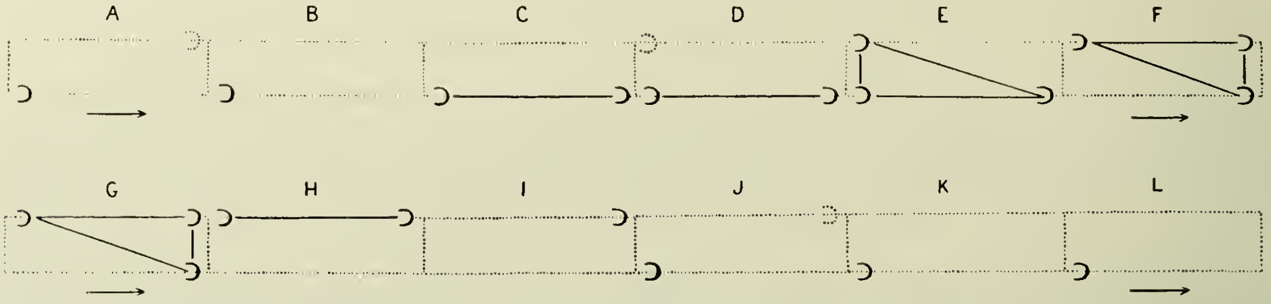


FIG. 466.—Chart of footprints made by a cob cantering. At A, the right hind foot is on the ground and the left fore foot near it. At B, the right hind foot is on the ground. At C, the right fore and hind feet support the body laterally. At D, the right fore and hind feet are on the ground and the left hind foot near the ground. At E, the body is supported by a posterior tripod formed by the right fore and the two hind feet. At F, the body is supported on an anterior tripod formed by the two fore feet and the left hind foot. At G, the body is a second time supported by an anterior tripod as at F. At H, it is supported laterally by the left fore and hind feet. At I, by the left fore foot. At J, K, and L, by the right hind foot (the Author).

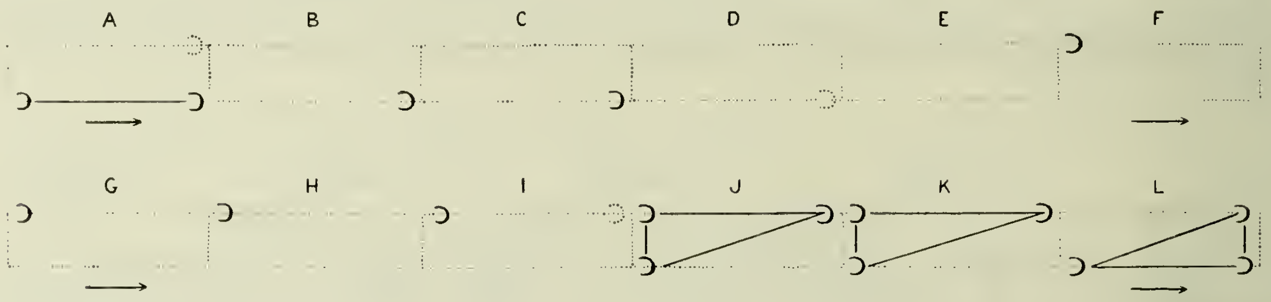


FIG. 467.—Chart of the footprints made by race-horse cantering. The chart is interpreted according to the explanations already given (the Author).

one of the easiest paces for the rider. The fall of the feet resembles that in the walk, but is more irregular, the body at intervals being unsupported. In beginning the pace the right or left fore foot generally leads, the diagonal hind foot following.

I append two charts of the footprints obtained from instantaneous photographs of a cantering cob and a cantering race-horse (Figs. 466 and 467). In these figures the dotted hoofs are near but not quite touching the ground.

§ 350. The Amble of the Horse.

The amble, like the canter, is an easy rolling movement with less vertical and more lateral and diagonal action. It is a favourite pace with many riders. It in some respects resembles the pace of the giraffe, where the two limbs of the one side move together and alternate with those of the other side. The amble is, according to some, a

modified and quickened walk. The feet, however, do not provide the tripod supports which they do in the walk. On the contrary, they act laterally and diagonally, chiefly the former.

I subjoin two charts of the footprints made by an ambling palfrey (Figs. 468 and 469).

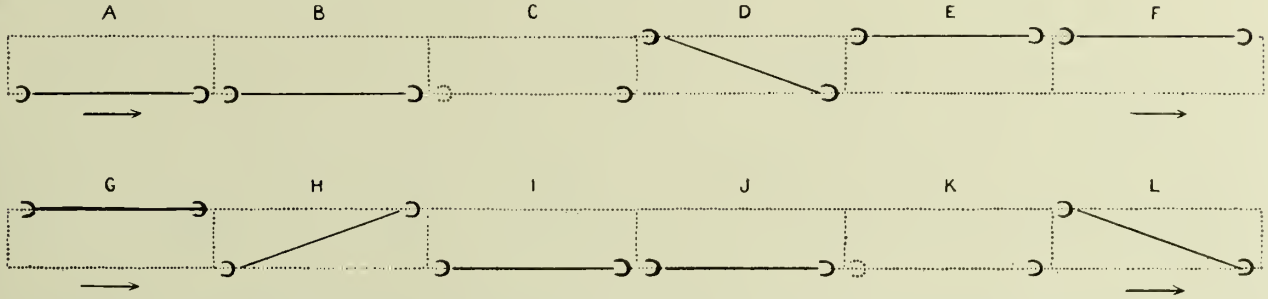


FIG. 468.—Chart of footprints made by an ambling palfrey. At A and B, the supports of the body are lateral, formed by the fore and hind feet of the right side. At C, the right fore limb gives the support, the right hind limb being near but not on the ground. At D, the body is supported diagonally by the right fore and left hind feet. At E, F, and G, it is supported laterally by the fore and hind feet of the left side. At H, it is supported diagonally by the right hind and left fore foot. At I and J, it is supported laterally by the right fore and hind feet. At K, by the right fore foot; the right hind foot being near the ground. At L, it is supported diagonally by the right fore and left hind feet (the Author).

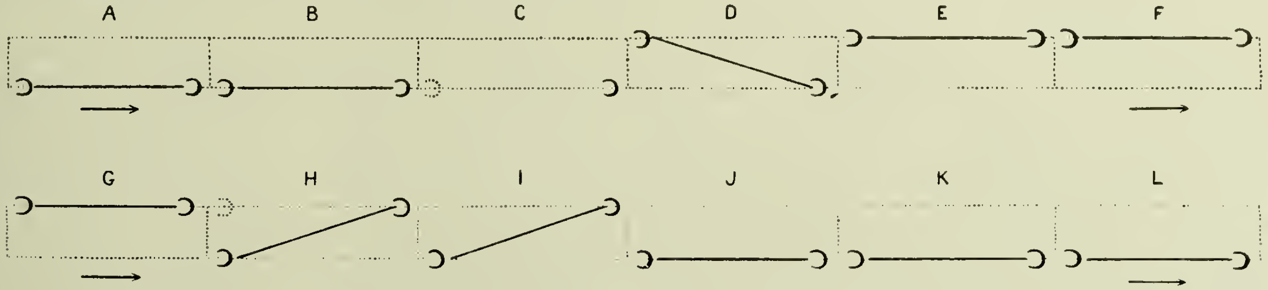


FIG. 469.—A second chart of footprints made by an ambling palfrey. This chart resembles that given in Fig. 468 and explains itself (the Author).

§ 351. The Rack of the Horse.

The rack may aptly be described as a fast trot. It is a vigorous, very rapid and exciting, uncomfortable pace indulged in by men who like fast trotting horses. It differs from the trot to the extent that the limbs and feet act for the most part laterally instead of diagonally. It is one of the paces of the Egyptian camel. A chart of the footfalls is given at Fig. 470.

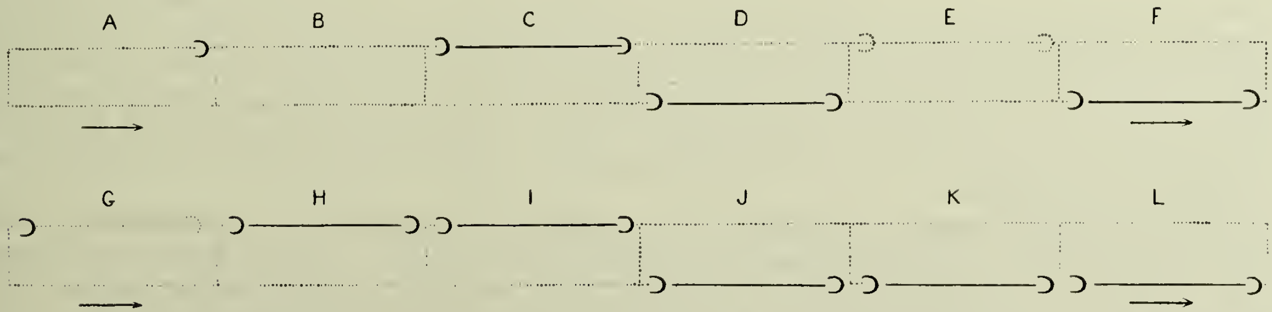


FIG. 470.—Chart of footprints made by a thoroughbred horse when racking. At A, the left fore foot only is on the ground. At B, the horse is in the air. At C, the body is supported laterally by the left fore and hind feet. At D, it is supported laterally by the right fore and hind feet. At E, the left fore and hind feet are near but not touching the ground. At F, the body is supported laterally by the right fore and hind feet. At G, the left hind foot only is on the ground, the left fore foot being near it. At H and I, the body is supported laterally by the left fore and hind feet. At J, K, and L, it is supported laterally by the right fore and hind feet (the Author).

§ 352. The Ricochet of the Horse.

The ricochet, strictly speaking, cannot be regarded as a pace of the horse. It is, at best, an occasional movement seen in jumping. The term ricochet literally means the rebounding and skipping of an object, as a cannon ball fired at a low elevation when it reaches the earth, or a flat stone leaping along the surface of water when

projected against it at a certain angle. It is, in animal mechanics, a kind of jumping or hopping witnessed in certain birds such as the sparrow, and in the kangaroo when travelling at a high speed by the aid of its powerful hind legs and enormous tail.

In the kangaroo the anterior extremities are greatly dwarfed, while the posterior ones and the tail are developed to quite an abnormal extent. The kangaroo literally advances *per saltum*. This it does by converting its huge hind limbs and giant tail into a tripod from which it projects itself into space by enormous bounds or jumps—each jump covering anything from 10 to 30 feet.

When a kangaroo is pursued it can readily out-distance horses and hounds for considerable periods. It is only in the gentler and slowest movements of the kangaroo that its anterior extremities take part. In the forced, rapid, violent movements, the great hind limbs and tail alone are engaged. In the slower, gentler movements, the anterior and posterior limbs apparently act together and in pairs and alternately ; the anterior extremities making one step and the posterior ones a second step. This, however, is a mistake, as a careful examination will show. As a matter of fact, the anterior and posterior extremities make lateral, diagonal, and tripod movements, as in the walk of the horse ; the movements being obscured by the disproportion between the anterior and posterior limbs, and by the lateral and diagonal movements being minimised. This is shown by the right and left hind limbs being slightly in advance of each other, and by their acting diagonally in the walk.

Even in the quick bounding movements the great hind legs do not act precisely at the same instant and abreast of each other. On the contrary, the right or left hind leg takes the lead in making the spring, precisely as in a horse when leaping. In the horse the right or left hind leg begins the spring, which is immediately followed by the dropping of the other hind leg, the great effort of jumping being made by both legs. The same thing happens when the horse alights. If the horse begins its leap with the right hind leg, the left fore leg first reaches the ground ; the right fore leg being dropped immediately after. The shock of alighting is sustained by both fore legs. When both fore legs are on the ground, the first hind leg to be dropped, when the horse is recovering itself, is the right hind leg ; this being the diagonal of the left fore leg which first reached the ground, and the leg from which the horse originally sprang. The leap of the horse (and the same may be said of the kangaroo) is therefore, strictly speaking, not a wholly antero-posterior movement, but an antero-posterior-diagonal movement. The horse when it begins its leap is in motion, and it could not possibly arrest its forward progress to place its two hind limbs exactly abreast of each other to make a, so to speak, square leap. The same remark applies to the action of the fore limbs in alighting.

On looking casually at the movements of a kangaroo one is apt, as stated, to believe that the anterior and posterior limbs act in pairs and alternately. This view is seemingly confirmed by the anterior limbs apparently working within the posterior ones, as in one phase of a dog when galloping. It is not really so, as I have satisfied myself from actual observation in the Zoological Gardens of London and those of Barcelona, Spain. A careful examination of the extremities of this quaint and interesting animal when walking will reveal the fact that one or other of the limbs leads in all forward movements where the four limbs are employed ; and this holds true also of the hind limbs when the animal is bounding forward at its greatest speed. In the walk and slower movements of the kangaroo the anterior extremities support rather than propel the body forward. In the more energetic bounding movements the great hind legs and ponderous tail at once support and project the animal *per saltum*, as stated.

The anterior and posterior limbs in the gentler movements referred to, afford two sets of supports, namely, an anterior set provided by the two anterior limbs which act more or less together, and a posterior set provided by the two posterior limbs which also act nearly consentaneously and together. In the slower movements the great tail scarcely comes into play.

Having described and illustrated the locomotion of the horse with considerable care it is not necessary to take up in succession the movements of the several tame and wild quadrupeds such as the ox, ass, sheep, goat, camel, deer, lion, tiger, &c. The locomotion of all these animals is to all intents and purposes identical with that of the horse. I will therefore conclude this section of the work by short references to the locomotion of the giraffe, elephant, and dog, which present slight peculiarities.

§ 353. Locomotion of the Giraffe.

In the giraffe in walking the two limbs of each side of the body move together and alternately. Thus the limbs of the right side of the body advance together in curves to form one step ; those on the left side of the body advancing together to form a second step. The lateral movements preponderate and take precedence of the diagonal and tripod movements. A certain degree of diagonal movement is, however, necessary to enable the animal to change the position of its limbs, which move alternately on the right and left sides of the body, as explained. In

the giraffe, locomotion is chiefly a lateral movement. There is little of the diagonal movement and less of the tripod one. The walk of the giraffe slightly resembles the rack of the horse ; the lateral movements being in the ascendant in both.

§ 354. Locomotion of the Elephant.

The elephant has two paces, namely, the walk and the amble. This huge animal is curiously enough provided with hind limbs which in many respects resemble the anterior ones. Thus the hind limbs do not as in all other quadrupeds bend backwards in flexion, but forwards as is the case with the anterior limbs. The elephant is consequently provided with what are virtually four knees. The feet too of the elephant are peculiar. They consist of large, flat, soft expansions with five toes which spread out at each step. In walking the heel or posterior part of each foot is first placed on the ground as in man. Of this I have fully satisfied myself from actual observation. Two men coupled together with an interval of five or six feet between, and walking out of step, give a wonderfully good representation of the locomotion of the elephant.

The reader will readily make out the walk of the elephant from an examination of Figs. 471 to 478 inclusive.

At Fig. 471 the two anterior and the left posterior legs and feet are on the ground. The animal is supported

FIG. 471. FIG. 472. FIG. 473. FIG. 474.

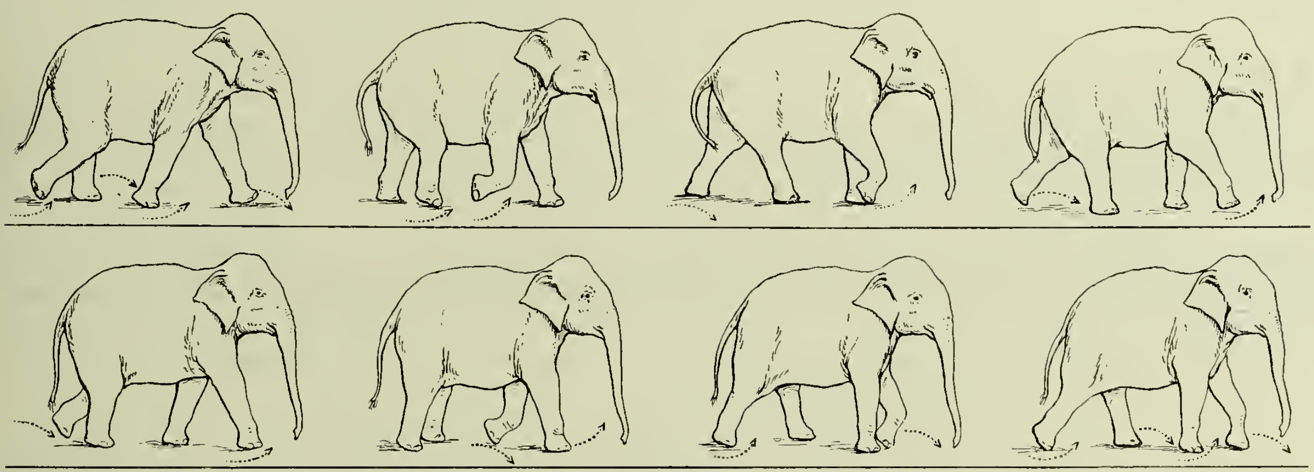


FIG. 475. FIG. 476. FIG. 477. FIG. 478.

FIGS. 471 TO 478.—Show the walk of the elephant.

by an anterior left tripod. The right fore foot is about to leave the ground and the right hind foot about to be deposited on it. At Fig. 472 the left fore and left hind legs and feet are on the ground and afford a left lateral support. The right fore leg is flexed and the foot is off the ground ; the right hind leg being nearly extended and the foot all but placed on the ground. At Fig. 473 the left fore and the two hind legs and feet are placed on the ground, and supply a posterior tripod support. The right fore leg is less flexed than in Fig. 472. At Fig. 474, the left fore and the right hind legs and feet are on the ground and a diagonal support provided ; the right fore and the left hind legs being nearly extended. At Fig. 475 the left fore and the right hind feet are on the ground and supply a diagonal support. In this figure the right fore leg is nearly extended and the foot in close proximity to the ground. At Fig. 476 the right fore and the right and left hind legs are fully extended, and the corresponding feet placed on the ground supplying a posterior tripod of support. At Fig. 477 the right fore and the right and left hind legs and feet are still on the ground, the right hind foot preparing to leave it. The left fore leg is less flexed than in Fig. 476. At Fig. 478, which is nearly the same as Fig. 471, the right fore and the right and left hind legs and feet are still on the ground ; the right hind leg and foot having all but left the ground, and the left fore leg and foot being more extended and about to be placed on it. It will be seen in this Fig. 478 that the toes of the right hind foot are the last part of the foot to leave the ground, just as the heel was the first part of the foot to touch the ground. The same holds true of the other three feet.

A comparison of the foot supports in the walk of the elephant with those in the walk of the horse will reveal practical identity in the two kinds of locomotion.

The amble in the elephant closely resembles that in the horse and need not be described separately.

§ 355. The Gallop in the Dog.

The walk and trot in the dog differ in no respect from similar paces in other quadrupeds. The gallop is peculiar in this, that the limbs in certain phases of it overlap to a great extent in an antero-posterior direction (Figs. 479 to 488).

At Fig. 479 the dog is supported by the left fore leg and foot, and at Fig. 480 by the right fore leg and foot. At Fig. 481 it is in the air; the anterior and posterior limbs being threaded through each other in a backward

Fig. 479. Fig. 480. Fig. 481. Fig. 482. Fig. 483.

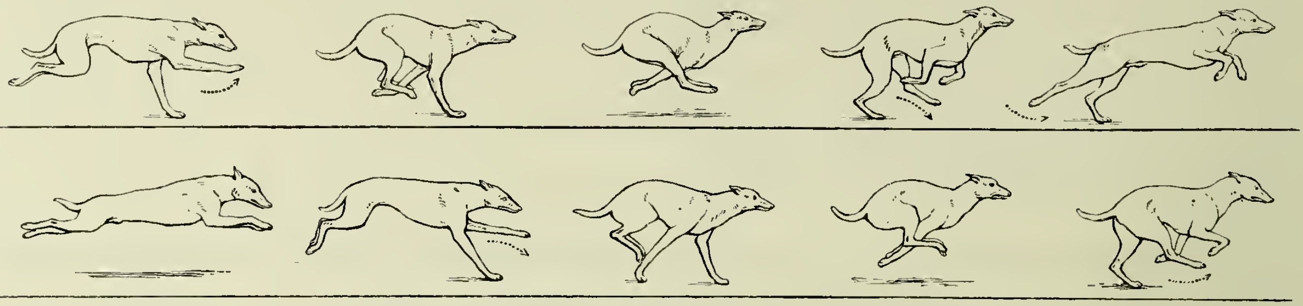


Fig. 484. Fig. 485. Fig. 486. Fig. 487. Fig. 488.

Figs. 479 to 488.—Represent the more striking phases in the gallop of the dog.

and forward direction to a remarkable extent. The threading referred to is also seen, though to a less degree, in the gallop of the fallow deer and in the walk of the kangaroo. At Fig. 482 the dog is supported by the right hind leg and foot, and at Fig. 483 by the left hind leg and foot. At Fig. 484 it is a second time in the air. At Fig. 485 it is supported by the right fore leg and foot, and at Fig. 486 by the two fore legs and feet. At Fig. 487 it is a third time in the air; the legs being threaded through each other as in Fig. 481. At Fig. 488 it is supported on the left hind leg and foot. Fig. 488, it will be observed, is the reverse of Fig. 482, and Fig. 485 is the reverse of Fig. 479. The other figures represent intermediate movements, necessary to a change of position in the limbs.

PROGRESSION ON AND IN THE WATER

If we direct our attention to the water, we encounter a medium less dense than the earth, and immensely more dense than the air. As this element, in virtue of its fluidity, yields readily to external pressure, it follows that a certain relation exists between it and the shape, size, and weight of the animal progressing along or through it. Those animals make the greatest headway which are of the same specific gravity, or are a little heavier, and furnished *with extensive surfaces*, which, by a dexterous tilting or twisting (for the one implies the other), or by a sudden contraction and expansion, or by quicker or slower movements, they apply wholly or in part to obtain the maximum of resistance in the one direction, and the minimum of displacement in the other. The change of shape, and the peculiar movements of the swimming surfaces, are rendered necessary by the fact, first pointed out by Sir Isaac Newton, that bodies or animals moving in water, and likewise in air, experience a sensible resistance, which is greater or less in proportion to the density and tenacity of the fluid, and the figure, superficies, and velocity of the animal.

To obtain the degree of resistance and non-resistance for progression in water, Nature, never at fault, has devised some highly ingenious expedients, the syringograde animals advancing by alternately sucking up and ejecting the water in which they are immersed; the medusæ by a rhythmical contraction and dilatation of their mushroom-shaped disc; the scallop by slowly opening and quickly closing its shell; the rotifera or wheel-animalcules by a vibratile action of their cilia, which, according to the late Professor Quekett, twist upon their pedicles so as alternately to increase and diminish the extent of the surface presented to the water, as happens in the feathering of an oar. A very similar plan is adopted by the pteropoda, found in countless multitudes in the northern seas, which, according to Eschricht, use the wing-like structures situated near the head after the manner of a double paddle, resembling in its general features that at present in use among the Greenlanders.

Other peculiar modes of swimming may be mentioned. The lobster swims tail first. By suddenly flexing and curving the posterior half of the body and expanding its broad tail-segment (the telson), it seizes the water

with a deeply concave surface and darts forward at an incredible speed. No one can realise the suddenness of the movement who has not actually witnessed it. The common cuttle-fish swims body first. The squids or calamars swim alternately head first and tail first. These beautiful white transparent creatures, which I had an opportunity of studying at the aquarium of Naples, tack about in the water in opposite directions by a series of sinuous flight-like movements very much as sea-gulls flit hither and thither in a land-locked bay. They might very well be taken for a mimic flight of gulls. The fish *Mormyrus oxyrhynchus* not unfrequently swims backwards for short distances by figure-of-8 movements of its pectoral fins and tail, which latter is mackerel-shaped. This is a Nile fish which I watched with great interest at the Gezirah Aquarium, Cairo. It develops beautiful double-curve, figure-of-8 movements at the free margin of its tail when swimming slowly. These movements, seen in the tails of all fishes, are particularly well marked in it. The common skate flies through, rather than swims in, the water. This it does by the flapping in a vertical direction of its greatly expanded radiating pectoral fins, which are made to undulate wave fashion ; the wave movements travelling from before backwards. The same is true of flat fishes generally. The angel-fish has also very large radiating pectoral fins. The smooth-hound, a small grey shark, is remarkable for the great development of its dorsal and ventral fins, and for its long heterocercal tail, which make it a powerful swimmer. The graceful swift swimming of young sharks and dog-fish can be conveniently studied at the Brighton and other aquariums in England.

The remarks made regarding the fins and tail of the shark apply equally to the saw-fish. The flying gurnard and flying-fish have greatly expanded pectoral fins ; the latter ever and anon betaking itself to the air after the manner of flying birds. The sea-butterflies (pteropods), as already indicated, flap a pair of transparent wing-like structures similar in many respects to the wings of insects.

The characteristic swimming movement is that adopted by fishes as a class, where the tail and posterior half of the body perform the principal part of the work.

The configuration of the skeleton and the muscular arrangements of the fish are specially designed to produce lateral, double curve, figure-of-8 movements in the body, and the same is true of the caudal and other fins. The swimming of the fish is also characterised by a slight rotation and twisting of the body and spinal column in the direction of their length.

The general appearances presented by ancient and modern fishes, and by their osseous and muscular systems, as well as the peculiarities of their caudal and other fins, and their manner of increasing and diminishing the size of the fins, &c., will be readily understood by a reference to Plates cliv., clv., and clvi., pp. 1161, 1166, 1168, which see.

The swimming arrangements in the fish, amphibian, bird, and mammal are given at Plate cliii., p. 1148.

PLATE CLIII

Plate cliii. A casual study of the figures of this Plate reveals the important fact that the size and shape of the swimming organs in the several orders of higher animals vary considerably, but that in all there is a common principle at work.

In some cases, they swim entirely by the aid of webbed hands and feet, in others partly by webbed hands and feet and partly by a swimming tail ; while in a third the great organ of propulsion is the broadly expanded caudal fin. The animals in this Plate, with the exception of those represented at Figs. 1 and 2, have been drawn for the author by C. Berjeau.

Fig. 1.—The beaver (*Castor fiber*). This interesting creature swims chiefly by its hind feet, which are large, powerful, and webbed. Its fore feet, which are much smaller and webbed, also take part in swimming, but they are likewise employed as digging, scraping organs and assist in beaver dam construction. The feet of the beaver resemble those of the otter and platypus, and are adapted to both land and water, but especially to water. The beaver is a splendid example of a swimming quadruped.

Fig. 2.—The walrus (*Trichechus rosmarus*). This quaint-looking creature has greatly enlarged webbed hands and feet known as flippers. Its fore and hind limbs are very considerably modified, so that they are adapted almost exclusively for water, and very little, if at all, for land. Both fore and hind limbs are short and are broadened out by the great divaricating power possessed by the digits, which enables the animal to increase and decrease its swimming surfaces at pleasure. The fore and hind limbs are also very loosely jointed, so that they can be readily flexed, extended, and tilted by well-developed straight and oblique muscles which at once secure flexion, extension, and semi-rotatory movements ; the latter being especially necessary in seizing and letting go the water in natation.

One of the fore limbs of the walrus is seen dissected at Fig. 4 of Plate clx., p. 1180, and a study of this figure satisfactorily shows how the fingers can be separated and the web between them stretched, or the converse ; how the limb can be alternately extended or flexed, and how the limbs can be tilted and rotated slightly so as alternately to seize and evade the water when swimming. Other Figs. in Plates clx. and clxi., p. 1181, show the same things in the sea-lion and seal.

Fig. 3.—The seal (*Phoca vitulina*). In this animal not only the limbs but also the whole body is modified to adapt it more perfectly to its manner of life. The anterior flippers are decreased and the posterior flippers increased in size ; the body becoming

PLATE CLIII

Fig. 1.

Fig. 2.

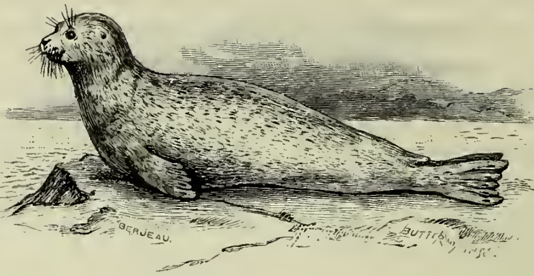


Fig. 3.

Fig. 4.

Fig. 5.

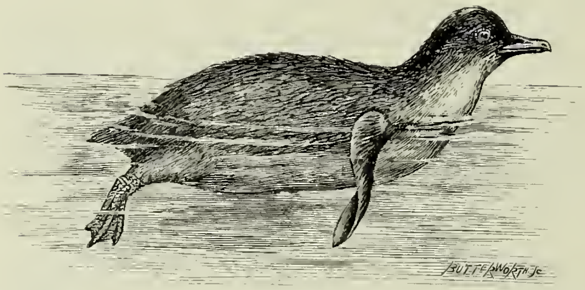


Fig. 6.

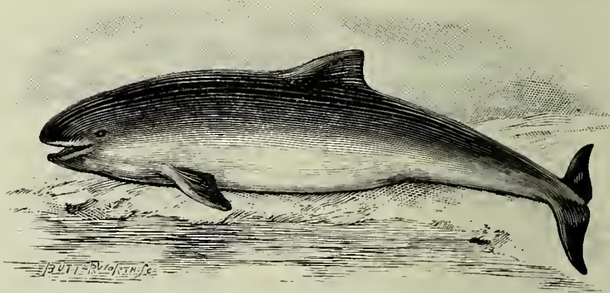


Fig. 7.

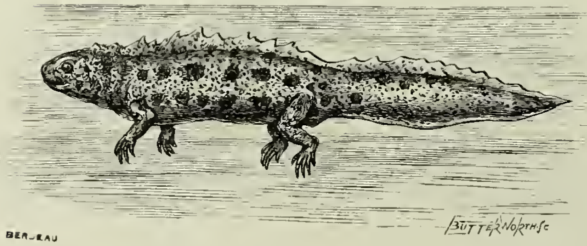


Fig. 8.

Fig. 9.

PLATE CLIII (*continued*)

more or less fish-shaped. The flippers of the seal in all respects resemble those of the walrus already described (Fig. 2); the action of the posterior flippers being identical with that of the caudal fin of the fish. They are vigorously lashed from side to side with a double curve figure-of-8 sculling motion; the flippers being fully expanded and partly closed at different points of the lateral strokes, as in the fish. The body of the seal is thrown into double curves in swimming, a peculiarity fully explained when describing the swimming of the fish. The seal has an odd habit of frequently swimming on its back.

Fig. 4.—The manatee (*Manatus americanus*). This sea-mammal even more than the seal has assumed the fish shape. The anterior flippers are fairly well developed, but the posterior ones have disappeared to make room for a broadly expanded swimming tail. It follows that the animal swims exclusively by its fine powerful tail, the anterior flippers being reserved for balancing, turning, and maintaining a semi-erect position. Fine dissections of the swimming appliances of the manatee are given at Fig. 2 of Plate clix.

Fig. 5.—The sea-bear. This mammal and its congener, the sea-lion, are distinguished for their comparatively very large and powerful anterior flippers, which they employ as flying organs in the water precisely as the penguin does. The sea-lion, by means of its anterior flippers, literally flies through the water, and at a great speed: the hind flippers performing quite a minor part in swimming, and acting, when set at right angles to the body, as a drag for slowing and regulating the forward movements. The great anterior flippers of the sea-lion are true wings as regards structure. Thus they are triangular elastic organs which are thickest at the root and along the anterior margin, and thinnest at the tip and along the posterior margin. They are beautifully graduated, and resemble, in all respects, the swimming and diving wings of the penguin and the flying wings of the insect, bat, and bird. When vigorously applied to the water in a line at right angles across the body they impel the animal forwards, and in an upward or downward direction as desired. The animal always progresses in the direction of the thick margins of the anterior flippers, and the angle of inclination of the flippers settles the precise course forwards, downwards, or upwards. Fine dissections of the anterior and posterior flippers of the sea-lion occur at Plates clx. and clxi., which see.

Fig. 6.—The little penguin (*Aptenodytes minor*). This quaint and active bird is provided with a double set of swimming appliances, namely, a pair of webbed feet like swimming birds generally, and a pair of small specially constructed wings which enable it to fly through the water with incredible rapidity. The feet are employed for swimming on the surface of the water; the wings for diving and flying through it in all directions. The wings resemble those of birds generally, in that they are triangular in shape, elastic, and thicker at the root and along the anterior margin than at the tip and along the posterior margin. They are peculiar in this that they are much smaller than birds' wings generally, less elastic, and covered with very minute feathers which on a hasty examination might be taken for tiny elongated scales. The aborted feathers have no functional significance, that is, they take no part in the wing movements. The wing of the penguin resembles the pectoral fin of the shark (Plate clvii., Fig. 10, p. 1170), and that of the Plesiosaurus (Plate clxiii., Fig. 2, p. 1187). All three are constructed on a common plan. The wing of the penguin occasionally acts as a screw, as represented in this figure. Its general appearance and action are fully explained at Plate clxiii., Fig. 1 (the Author).

Fig. 7.—The porpoise (*Phocæna communis*). Here we have a genuine mammal conforming to the fish-shape and fish mode of swimming; the only difference being that the porpoise causes its caudal fin or tail to oscillate from above downwards, instead of from side to side. The porpoise is often mistaken for a fish, of which it has all the outward signs, namely, greatly reduced anterior flippers (pectoral fins), a dorsal fin, and a beautifully modelled and a very powerful swimming tail. The tail with the posterior half of the body forms one of the most effective propellers known. The porpoise is admittedly one of the fastest of sea mammals; its speed being such as to enable it to gambol and play about the bows of the swiftest ocean-going steamer, steaming its best. Its elegant shape, strong muscular system, and finely formed, well poised tail, sufficiently account for its swimming powers. It is a rare treat to see it in its native element pursuing in frolic one of its own kind equally intent on amusement. It is downright exciting to see a shoal of them dashing wildly about in pursuit of their favourite food fishes. In this case the idea of power is added to that of speed, and the scene is converted into a veritable battlefield where one is conscious of indiscriminate slaughter on a wide scale.

Fig. 8.—The triton (*Triton cristatus*). In this common amphibian the animal is provided with four swimming legs and feet fairly adapted for the land, and a huge swimming tail which makes it perfectly at home in the water. The triton, as far as its powers of locomotion go, resembles the crocodile. It also resembles the developing frog when in its advanced tadpole condition. The tail is the chief swimming organ, and is made to lash from side to side like the tail of the fish. The triton affords another example of figure conforming to function when its mode of life is considered. It spends part of its time on land and part in the water, and is accordingly provided with two different kinds or sets of travelling organs.

Fig. 9.—The salmon-trout (*Salmo trutta*). This may be regarded as a typical example of a well-formed, well-endowed swimming fish. Its shape and all its parts contribute to successful swimming. It is provided with two pectoral, two dorsal, two ventral, an anal and a caudal or tail fin. The general contour of the fish, and the size, shape, and position of the fins make for efficiency. It is a swift, elegant, and strong swimmer, as all anglers know. It is not necessary to enter into the manner of its swimming, the swimming of the fish having been fully gone into in a previous part of the work.

In order fully to comprehend the peculiarities of the several kinds of swimming referred to above, it is necessary to deal with them separately and in detail, beginning with the more simple.

§ 356. The Swimming of the Jelly-Fish.

While the higher aquatic animals display in their swimming organs wonderful mechanical adaptation all dominated by a common principle, the lower aquatic forms have each their peculiarities culminating in arrangements equally suggestive of law, order, and design, as far as their several modes of natation are concerned. The medusa or jelly-fish swims along the surface of the summer sea by a series of centripetal and centrifugal wave movements of its mushroom-shaped disc. When it opens or expands its disc, which it does voluntarily, it draws in the water in which it is immersed into a more or less conical-shaped cavity. This constitutes the non-effective or back stroke. When it suddenly and vigorously contracts or closes its disc, it forces in a backward direction a practically incom-

pressible conical-shaped mass of water, from the surface of which it glides in a forward direction. The backward thrust given to the water constitutes the effective or forward stroke. The more sudden the contracting or closing movement, the greater the swimming power developed. The movements which are voluntary in character are due to muscular action regulated by nerves. There are few more beautiful sights in nature than the swimming of the jelly-fish on a warm summer day. Its leisurely graceful progress near the surface of the ocean, accompanied as it is by a wealth of iridescent colour, suggests to the mind the idea of a luxurious easy life, and enjoyment of a high order.

I had frequent opportunities when on yachting excursions with my late lamented friend, Dr. John Duncan of Edinburgh,[1] on Loch Hourn, West of Scotland, in August, 1899, of observing and analysing the swimming of all kinds of jelly-fishes, both in the free and captive state.

As I took careful notes of the swimming day by day, I cannot do better than transcribe them in their original form.

They are briefly as follows : 1. The jelly-fish in swimming moves upwards, downwards, or sideways at discretion. 2. It progresses by centripetal and centrifugal voluntary wave movements. 3. When it closes or contracts its disc, it reduces its size by about a quarter. 4. The closing movement begins in a portion of the disc—not necessarily always the same portion—and spreads by a wave movement so rapid as to appear simultaneous. 5. The closing movement is at first energetic and sudden, and becomes slower towards the termination of that act ; the opening movement is less pronounced and more regular and resembles the flowing of water. The closing and opening movements are deliberate and methodical, as well as voluntary. They are co-ordinated purposive movements, and vital in their nature. 6. The closing movement occupies less time than the opening one. 7. The observer can count three while the disc closes, and four while it opens. 8. Between the closing and opening movements there is a pause when he can count one. 9. The disc closes twenty times per minute. 10. The disc closes and opens in a manner greatly resembling that by which the several compartments of the heart close and open ; that is, there is a comparatively sudden and vigorous movement, followed by a pause and a slower, more regular, continuous movement. Similar remarks apply to the action of voluntary muscles. 11. The movements of the jelly-fish are rhythmic in character and fundamental, and are due to combined muscular and nerve action. 12. They are at once typical and vital. 13. They occur apart from stimulation of any kind—the sea water investing and affecting all parts of the animal equally. The same water (even if it did act as a stimulus) could not produce diametrically opposite results ; it could not cause the jelly-fish to close or contract its disc the one instant and open or dilate it the next. It could not, under any circumstances, establish rhythmic movements. 14. The disc consists of rudimentary neuromuscular layers, but there are no fixed points for the origin and insertion of muscles in the ordinary sense. 15. The mass of the animal, because of its centripetal and centrifugal movements, appears to pulsate or throb in two different directions. 16. During the closing contractile centripetal action, it imprisons a conical-shaped portion of water by its disc, from which it forces itself in an upward, downward, or forward direction. 17. During the opening dilating centrifugal action it lets go, and, so to speak, frees itself from the water included within its disc. 18. By alternately seizing and letting go the water, it progresses somewhat slowly and irregularly. 19. The centripetal and centrifugal movements are seen to most advantage when the animal is placed on its back. The movements in question are, in no sense, dependent on each other ; they are equally vital in their nature. 20. The opening movement is not primarily due to elasticity—indeed elasticity takes next to no part in it. This is evident from the fact, that there is no jerky motion at the beginning of the centrifugal act, which there would be if it were due to elastic recoil. 21. The centripetal and centrifugal movements of the jelly-fish foreshadow those of the involuntary and voluntary muscles.

I append supplementary notes of a second series of observations on the swimming of the jelly-fish made by me in the famous aquarium at Naples in March, 1904. They confirm my previous notes (1899) already given. 1. The swimming is produced by the alternate centripetal and centrifugal wave movements of the umbrella-shaped disc. 2. The advance in any particular direction immediately follows the centripetal movement. 3. The opening centrifugal and the closing centripetal wave movements of the disc are progressive in character. 4. When the disc is

[1] John Duncan, M.A., M.D., LL.D., F.R.C.S., was one of my oldest and most cherished Edinburgh University friends. He was a man of extraordinary ability, and was easily first in everything he tried. As a student he excelled in every kind of athletic sport. In after life he distinguished himself as a deer-stalker and salmon-fisher, and he could always give a good account of himself on the grouse moor. He was a first-rate classical scholar, and, at an early age, became noted as a brilliant teacher and operator in surgery at the Royal Infirmary of Edinburgh. He was especially remarkable for his acumen and great diagnostic power, and his surgical and other writings are characterised by much force and purity of style. He was at once the scholar and the gentleman, and a universal favourite with his colleagues and pupils. With a handsome face and tall, powerful frame, he combined much gentleness of disposition and a gracious manner which secured him friends wherever he went. Being a man of ample means he virtually kept open house, and his hospitality was crowned by the presence of a most amiable, beautiful, and warm-hearted wife. In town and country there was always the same cordial and effusive welcome. It was my good fortune to spend part of my autumn holiday with him and his charming partner at their shooting and fishing quarters in the Highlands every other season. They have, alas, both gone over to the majority. Dr. Duncan died suddenly from heart failure on the 24th of August, 1899, ten days after my last visit to him and his family, at Kinloch House, Skye, at which time a heavy shadow fell upon me. The friend has gone but the shadow remains.

closing or contracting a wave movement spreads from the centre of the disc in the direction of its periphery, which it purses up wave-fashion. 5. Conversely, when the disc is opening or dilating, the wave movement is reversed.

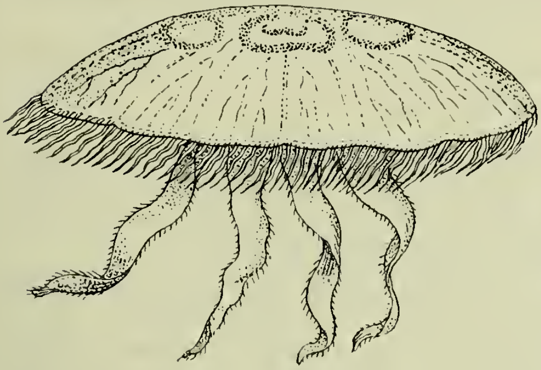


FIG. 489.

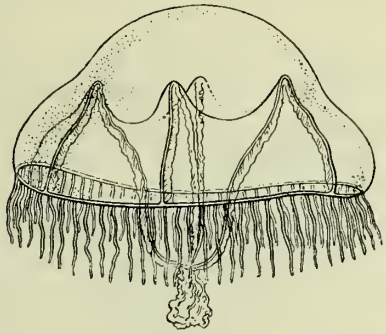


FIG. 490.

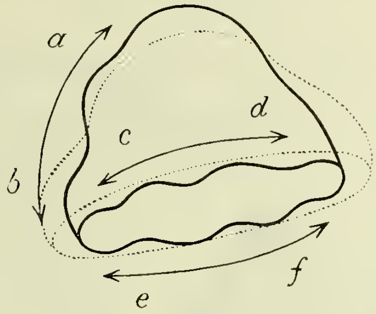


FIG. 491.

FIG. 489.—Lateral view of the British jelly-fish (*Aurelia aurita*). It occurs in large numbers in the Scottish seas in late summer and early autumn. It is transparent with the exception of the four gonads, which are of a beautiful violet blue (after Masterman).

FIG. 490.—Jelly-fish (*Tima flavilabris*) found in the bay of Naples. Exhibited in the aquarium of the Zoological station of Naples (Aquarium Guide-book).

FIG. 491.—Life study by the Author of the swimming movements of the jelly-fish (*Tima flavilavris*) as witnessed in the aquarium at Naples. The heavy solid line and the double-headed darts indicate the direction and locality of the wave movements which occur in the umbrella-shaped disc during the closing and opening of the disc. The dotted line gives the outline of the jelly-fish when at rest. *a, b, c, d, e, f*, Centripetal wave movements observed in the disc when it closes ; *f, e, d, c, b, a*, similar but opposite wave movements (centrifugal) occurring in the disc when it opens. These movements are voluntary, rhythmic, and progressive, and can readily be followed (drawn by the Author).

I give drawings of a common British jelly-fish, and of a jelly-fish from the bay of Naples, with a diagram showing the swimming movements of the latter (Figs. 489, 490, and 491).

The swimming of the jelly-fish affords an example of action and reaction, as between a living moving creature and the water, of the simplest and most direct kind.

§ 357. The Swimming of the Scallop (*Pecten*).

A similar arrangement obtains in the swimming of the scallop. This bivalve opens its shell leisurely and admits a wedge-shaped portion of water. This inaugurates the swimming movement and constitutes the non-effective or back stroke. The water so admitted into the shell is then suddenly and forcibly extruded, with the

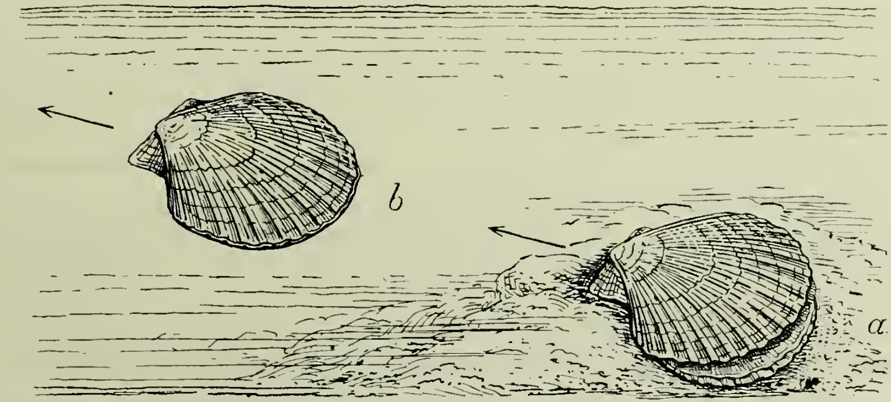


FIG. 492.—Scallop (*Pecten*). *a*, Scallop with its shell opened to admit a wedge-shaped portion of water. When the scallop suddenly closes its shell, it ejects the water in a backward direction and obtains a forward recoil as indicated at dart ; *b*, scallop swimming forward (the Author).

result that the scallop darts forwards in the direction of the hinge of the shell. The forcible extrusion of the water constitutes the effective or forward stroke. The opening and closing movements of the shell take place rhythmically and at regular intervals ; the animal advancing by a series of jerks.

The movements are centrifugal and centripetal as well as rhythmical in character. They are also voluntary

and perfectly under control; the scallop being able to swim in any desired direction—upwards, downwards, and horizontally. It is no uncommon thing to see the scallop make for and deposit itself on a rocky ledge, high above it. When the movements of the scallop are studied for considerable intervals, one is struck with their extent and variety (Fig. 492).

§ 358. The Swimming of Salpa cristata, one of the Syringograde Animals.

In the syringograde animals, swimming is also a question of action and reaction, but in another form. These curious animals alternately suck in and eject the water in which they are immersed. The sucking in of the water is performed slowly and constitutes the non-effective stroke; the sudden and forcible ejection of the water, so sucked in, constitutes the effective stroke (Fig. 493).

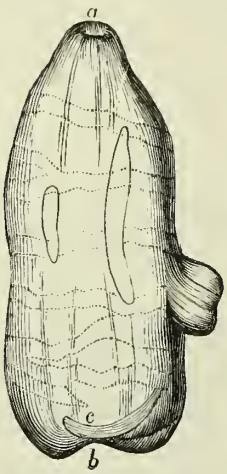


Fig. 493.—*Salpa cristata.* *a*, Orifice at mouth; *b*, orifice corresponding in situation to anal aperture; *c*, valve guarding orifice *b*, which permits water to enter in the direction of the mouth, but prevents its return in an opposite direction.

All this is on strictly mechanical lines. The Salpa resembles the single heart of the lobster or one of the compartments (auricle or ventricle) of a compound heart. It is endowed with a centrifugal and a centripetal power which enables it to draw in and eject fluid alternately. The water ejected produces a well-marked reaction on a principle discovered by Hero of Alexandria (*circa* 150 to 100 B.C.). This well-known mathematician and mechanician devised a steam-engine which was made to rotate by causing the steam to issue from its interior in an oblique backward direction; the reaction produced on the air by the escaping steam causing the engine to travel in an opposite or forward direction.

In Hero's engine the steam escaped *directly* into the air which formed a fulcrum for the rotatory movements. The same principle is at work in the Hon. C. A. Parson's modern turbine engine, with the difference that in the turbine the steam is made to escape *indirectly* and not before it has given off nearly all its power and is exhausted. The indirect escape is secured by causing the steam to pass through a labyrinth of ingeniously constructed passages on its way to the outlets. The turbine is, consequently, a much more economical engine than that of Hero. As an example of the principle of action and reaction in ship propulsion may be cited the water-jet engine, which alternately sucks in and ejects the water in which the vessel is immersed. I saw, some years ago, a large ship so propelled in the estuary of the Thames. The principle of Hero's engine, Parson's turbine, and the water-jet engine is, in all respects, similar to that employed in the swimming of the syringograde animals. The mechanics of nature and those of the engineer are, to all intents and purposes, identical. As a matter of fact, man cannot invent what does not exist in nature in some form or other.

§ 359. The Swimming of the Octopus.

The octopus (*Octopus vulgaris*) in swimming combines the wedge and syphon actions and the sinuous movements seen in the swimming of the fish. Thus the web of the octopus, which is situated near the head and connects the arms, is alternately spread out or opened, and brought together or closed, during the non-effective and effective strokes as in the jelly-fish. The syphon ejects water and so begets a reaction from the surrounding water, and the arms develop sinuous movements which considerably augment the propulsive efforts.

The spreading and closing of the web, the separating and bringing together of the arms, and the opening and closing of the syphon are thoroughly under control. These several acts combine to produce the non-effective and effective strokes.

The octopus swims backwards or body first, and when the arms are made to converge, as in the effective stroke, and are making sinuous double curves, they resemble so many eels pursuing the retreating body which they can never overtake.

The octopus is provided with a powerful muscular mantle which enables it alternately to draw in and extrude the water in which it swims. The water thus made to pass in and out is, when the animal is resting, employed in respiration. When it is swimming, part of it is made to pass through the syphon, which thus becomes an active agent in propulsion (Fig. 494).

The syphon, while it plays an important part in the swimming movement, largely determines the direction of the swimming. The syphon is mobile and can be bent in any direction—backwards, forwards, outwards, inwards, upwards, downwards, &c. The jet of water which issues from it can be turned in any of the directions indicated,

and the line of advance regulated. When the syphon is bent directly downwards and curved backwards, the jet of water issuing from it serves to propel the animal directly forwards as in cuttle-fishes (*Sepia*) and in squids (*Loligo*).

Three things contribute to the swimming of the octopus; (*a*) the sudden and vigorous contraction of the mantle or web at the roots of the arms; (*b*) the jets of water which emanate from the syphon; and (*c*) the sinuous movements of the arms. The swimming movement is a compound co-ordinated one, rhythmic in character. It further consists of stages marked by centripetal and centrifugal action. Thus when the mantle or web near the head vigorously contracts or closes, the syphon ejects its charge of water, and the arms come together and display undulatory movements. These movements, centripetal in character, constitute the effective or forward stroke. Then there is a brief pause, followed by the slow opening of the mantle or web and arms, and the sucking in of water to supply the syphon for a fresh discharge. The slower movements, centrifugal in character, constitute the non-effective or back stroke. The centripetal and centrifugal movements referred to occur rhythmically so long as the octopus continues to swim.

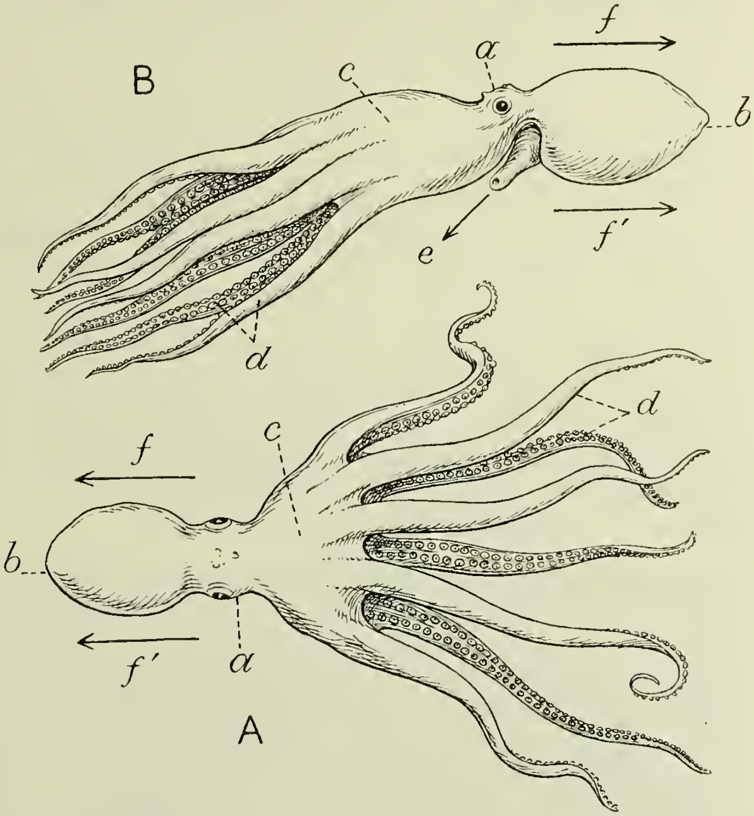


FIG. 494.—Shows the opening and closing movements of the swimming web and arms of the octopus (*Octopus vulgaris*).

A. The arms when spread out as in the non-effective or back stroke. *a*, Head of octopus; *b*, body of ditto; *c*, swimming web; *d*, dorsal and ventral surfaces of arms—the latter with suckers; *f*, *f′*, the line of advance.

B. The swimming web and arms when brought together and thrown into wave and double curves as in the effective or forward stroke. *a*, Head of octopus; *b*, body of ditto; *c*, swimming web; *d*, dorsal and ventral surfaces of arms—the latter with suckers; *e*, syphon; *f*, *f′*, line of advance. (Drawn for the author by C. Berjeau.)

The octopus sometimes grows to a large size, and might, if so disposed, prove a very dangerous antagonist. It is, however, unless when provoked and irritated, a timid animal, concealing itself among rocks and feeding upon crabs and molluscs. There is no authentic information of its ever having attacked a human being or a boat, notwithstanding the thrilling tales invented by Victor Hugo to the contrary. In the West Indies and the Mediterranean the *Octopus vulgaris* sometimes reaches a length of nine feet, and weighs as much as sixty-eight pounds; while the *Octopus punctatus* of the Pacific coast attains a length of sixteen feet—the body measuring a foot in length, with a diameter of six inches—and a radial spread of twenty-eight feet. (" The Riverside Nat. Hist.," vol. i. p. 371.)

§ 360. The Swimming of the Squid.

The squid or calamar (*Loligo vulgaris*)—a form of cuttle-fish—is a most interesting and attractive object. I enjoyed exceptional opportunities of studying it in the living condition in the tanks of the famous aquarium at Naples in 1904. It measures from seven to eight inches in length, is white and perfectly transparent with the exception of the eyes, which are about the size of sloes, and very dark and prominent. When its arms are brought together, as they are in swimming, the squid is fish-shaped. The animal is provided with two lateral, triangular, highly mobile fins which extend on either side of the posterior half of the body and resemble the caudal fin of certain fishes. These fins are remarkable structures, and are endowed with a wide range of vertical movement; the free margin of each fin during the up and down strokes passing through an angle of 125° or thereby. While the lateral triangular fins are making wide vertical sweeps, they develop in their substance and free margins double curve sinuous movements. The lateral triangular fins are the chief organs of propulsion. When the squid is swimming, they perform a series of steady vertical winnowing movements (sixty to the minute), and the extraordinary feature about them is, that they can cause the squid to swim in two diametrically opposite directions; namely, tail first or head first. In swimming, say from right to left, head first, the head and body of the squid are directed slightly upwards in the direction of travel. When the end of the tank is reached everything is reversed by causing the

head to dip and the tail and body to rise. The squid is now ready to swim from left to right, tail first. The lateral triangular fins propel the squid head first and tail first with equal ease and facility. The vertical winnowing movements of the lateral triangular fins are equally steady in swimming from right to left and from left to right. There is no jerkiness in either direction. The winnowing lateral fin movements are aided by a syphon

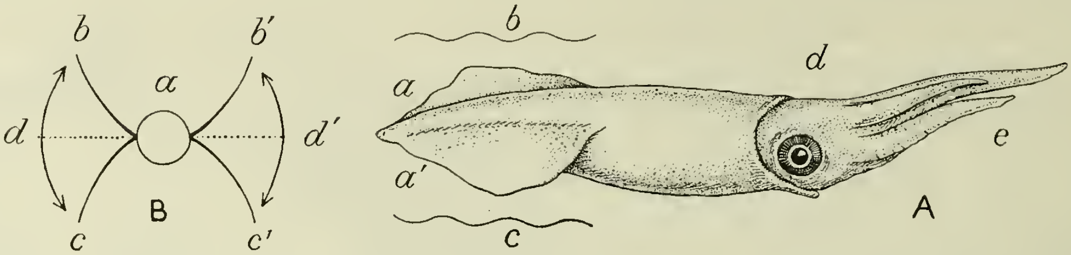


FIG. 495.—Shows the shape of the young squid or calamar (*Loligo vulgaris*) and the range of movement of its lateral triangular fins.
A. *a*, *a′*, Position and appearance of the lateral triangular fins occurring on the posterior portion of the body; *b*, *c*, undulations or waves made by the fins when making the vertical upward and downward winnowing movements; *d*, head; *e*, arms.
B. Transverse section of the posterior portion of the body of the squid with the lateral triangular fins attached. *a*, Transverse section of the caudal portion of the body; *b*, *b′*, position of the fins at the end of the up strokes; *c*, *c′*, position of the fins at the end of the down strokes. At the end of the up and down strokes the fins are directed towards each other and present concave surfaces (*b*, *b′*; *c*, *c′*); *d*, *d′*, double darts indicating the paths made by the free margins of the fins. The fins make wide vertical sweeps and pass through an angle of 125° or so. The action of the fins is alike vigorous and effective. (Drawn from nature by the Author.)

FIG. 496.—Life study of the swimming of the squid by the Author, as witnessed at the aquarium of the Zoological station of Naples. Drawn by C. Berjeau from original sketches for the present work. At the top of the figure the squids are swimming or flying from right to left *head first* (*vide* upper arrow). At the bottom of the figure they are swimming or flying from left to right *tail first* (*vide* lower arrow).

action, and by slight sinuous movements in the arms when the squid swims head first, but the main organs of propulsion are doubtless the lateral fins themselves. The general appearance presented by the squid is given at A of Fig. 495, and the movements made by the lateral triangular fins are indicated at B of the same figure.

There are few more dainty sights than the swimming or rather flying of small shoals of young squids in a large tank filled with pure sea-water. Their white delicate and transparent bodies and their winnowing flight-like movements greatly resemble a mimic flight of gulls beating seaward.

Their mode of swimming or flying is peculiar. As indicated, they swim alternately head first and tail first, mainly by the undulatory wave movements of the lateral triangular fins situated on the posterior portion of the body. They all swim in the same direction until the end of the tank is reached, when as if by preconcerted signal, they reverse their course and swim in an opposite direction. The body is inclined at an upward angle of 25° degrees or so when they swim, and the tilt of the body is reversed when they change their course at either end of the tank. In changing their course they do not wheel round, as one would naturally expect, but simply reverse the angle of inclination made by the body. Thus, when they swim from right to left of the spectator, the body is slanted, the head being uppermost. In this case they swim head first. When, on the contrary, they swim from left to right, the body is slanted in an opposite direction, the tail being uppermost. In this case they swim tail first. The swimming of the squid is very puzzling, but a careful analysis of it has convinced me that the true explanation is to be found in the lashing double curve movements made by the lateral triangular fins situated on the posterior part of the body ; these movements being reversed when the upward angle of inclination made by the body is reversed at either end of the tank. The fins in question have the power of reversing their wave movements and working in two directions, and the body can alternately make a forward and a backward angle with the surface of the water. The fins in swimming strike downwards and forwards as do the wings of insects, birds, and bats in flying.

Indeed the swimming of the squid is a form of flying. In this respect it resembles the swimming or flying of the skate and other flat fishes already described.

The points adumbrated will be readily understood by a reference to Fig. 496.

While the squids swim chiefly by means of two large powerful flexible triangular fins placed on either side of the posterior part of the body, one of the medusæ (*Ocyroë crystallina*) and the sea-butterfly (pteropod) swim by the aid of two wing-like structures situated near the head, as shown at Fig. 497.

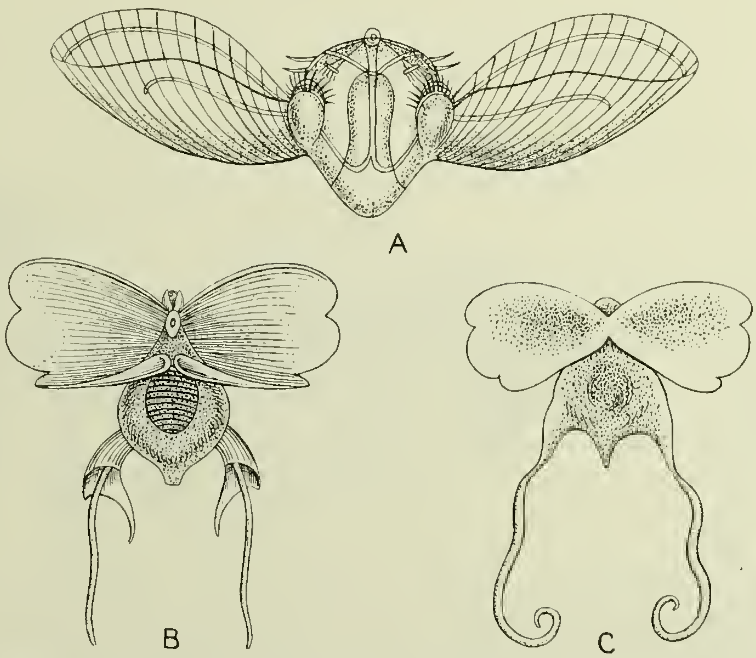


FIG. 497.—Furnishes examples of comparatively low forms provided with wing-like structures which enable them to fly in the water.
A. A rare and little known form of medusa (*Ocyroë crystallina*) which swims or rather flies by means of its wing-like structures.
B, C. Adult and immature forms of the sea-butterfly (*Hyalea tridentata*), exhibiting large wing-like structures which enable them to fly in the water very much as a bird flies in the air.

§ 361. The Swimming of the Winged-Medusa and Sea-Butterfly.

The genus *Ocyroë* to which the winged-medusa belongs occurs in the Gulf of Mexico and the Carribean Sea. It is comparatively little known, has a transparent body, and, attached to it, a pair of structures remarkably resembling true wings.

The wing-like structures are extended laterally—one on either side of the body—and when the animal is at rest they are spread out and motionless. When, however, it swims (or rather flies), the wings are raised high above the body and suddenly swung downwards and made to sweep through an angle of 180° or thereby. The *Ocyroë* flaps its two wings simultaneously as a bird does, and, as was to be expected, makes very considerable progress in the water (Fig. 497 A).

The sea-butterflies (*Hyalea tridentata*), found in large numbers in the northern seas, are very active little creatures, and are provided with two comparatively large wings. Like the other members of the group to which they belong they are carnivorous, and consume immense numbers of microscopic animals. They swim, or rather fly, in a very erratic manner, and are continually darting hither and thither in search of food. They turn and wheel suddenly in any and every direction, and their agility in the water is, in some respects, truly remarkable (Fig. 497, B and C).

The wing-like structures referred to in the squids, the medusa, and sea-butterfly, show how very closely the structures in question are allied to true wings, as seen in insects, birds, and bats.

In the squids, the swimming or, as some will regard it, flying, is uniform and steady. In the winged-medusa and sea-butterfly, on the other hand, it is irregular, erratic, and jerky. This is particularly the case in *Hyalea tridentata*.

§ 362. The Swimming of the Lobster.

The swimming of the lobster (*Homarus vulgaris*) is so peculiar that, in order to understand it, a brief reference to the anatomy of that interesting and highly-prized crustaccan becomes a necessity. This is especially the case as regards the tail-piece of the animal, which is elaborately constructed with a view to its being alternately expanded and closed during the effective and non-effective strokes in swimming.

The general appearance of the lobster is given at Fig. 498.

The body of the lobster reveals a remarkable assemblage of curiously constructed parts, among which are to be noted two sessile eyes, two antennæ and two antennules, two great claws or pincers for seizing and breaking up food, a cephalo-thoracic carapace or shield, six abdominal imbricating armoured segments, a telson or tail-segment, eight legs, and ten swimmerets with double paddles, the last of all being expanded to form with the telson the tail-piece or "caudal fin." The claws and abdominal segments contain large powerful muscles; and well-developed muscles occur in the legs, swimmerets, telson, and elsewhere. The several joints in the lobster are ingenious to a degree, and display marvellous constructive skill and resource. They combine wonderful mobility with a system

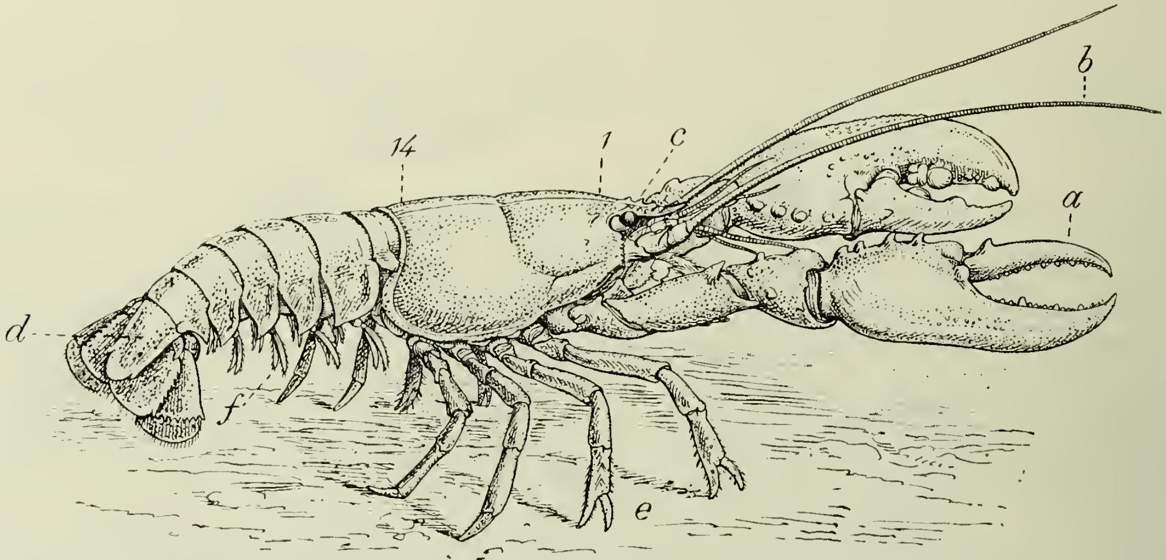


FIG. 498.—The common lobster (*Homarus vulgaris*) as seen walking. *a*, Claws; *b*, antennæ; *c*, head, eye, and antennules; *d*, telson; *e*, legs (four pairs); *f*, swimmerets; 1, the cephalo-thoracic shield or carapace (rigid); from 14 backwards, the imbricating abdominal segments (movable). (Drawn from life for the present work by C. Berjeau.)

of gags or stops which limit the degree of movement at certain points and in particular directions. The legs of the lobster can be made to move in almost every direction, and are capable of endless acts of partial and complete flexion and extension. In the water the animal is instinct with life; all its parts being constantly in motion—eyes, antennæ, claws, legs, swimmerets, abdominal segments, telson, &c.

The anatomy of the swimming parts of the lobster is given at Plate cliv., Figs. 1 to 5, p. 1161. The lobster, if its external skeleton, claws, limbs, swimmerets, tail-piece, powerful muscular system, wonderful arrangement of joints, &c., be taken into account, is one of the most remarkable of zoological products.

It belongs to the Crustacea, and is divided into twenty segments; the first thirteen segments forming the cephalo-thoracic portion of the animal—the remaining seven segments forming the abdominal portion (six segments), and the telson (one segment). The carapace is slightly curved from above downwards and is unyielding in all its parts. From the under or ventral surface of the cephalo-thoracic portion of the lobster, a pair of formidable claws, and eight jointed legs (four on each side) proceed. The latter enable the animal to move about with considerable celerity and freedom on the bed of the ocean.

From the under surface of the abdominal segments (16, 17, 18, and 19) four pairs of loosely jointed swimmerets with double paddles depend.

Each swimmeret is composed of the following parts:—

(*a*) A fibrous joint which connects it with the ventral surface of the abdominal segment to which it belongs and which permits very free motion.

(*b*) An appendage hollow, and hard, containing muscle.

(*c*) A pair of leaf-shaped paddles fringed with stiffish hairs and jointed to the appendage.

The swimmerets aet as miniature paddles and assist the forward movement when the lobster is walking on the bottom of the sea. They also, in the female, serve to lodge and proteet the ova while being hatehed out.

The leaf-shaped double paddles are eonvex anteriorly and deeply eoneave posteriorly. They taper, and are thieker at their roots than at their free extremities. They are, in this sense, true swimming organs. They elose or fold during the non-effeetive strokes and open out and separate during the effeetive strokes. When a pair of swimmerets are seen in their normal position, from before or behind, they greatly resemble miniature duek legs and feet (Plate eliv., Fig. 1, F).

The swimmerets move in pairs, and their leaf-shaped paddles can aet separately or in combination with the leaf-shaped paddles of the opposite side. The swimmerets move very rapidly and more or less rhythmieally; the baekward stroke, whieh is the effeetive one, being delivered with greatest foree. The swimmerets are designed to propel the lobster head first. They form, as indieated, a not unimportant auxiliary in walking. They, however, take no part in the normal swimming of the lobster, whieh is effeeted by the sudden and powerful eurvature, in a direetion from above downwards and forwards, of the broadly expanded tail-pieee in conjunction with the abdominal or posterior museular segments of the body. The violent eurving of the tail-pieee and posterior segments of the body eauses the lobster to dart forwards, *tail first*, with ineredible rapidity. The rapidity of the movement is at onee a revelation and a surprise, and is eaused by the sudden eontraetion of the great museular masses whieh oecupy, throughout their entire extent, the several abdominal or posterior segments and the telson itself.

The seven abdominal segments including the tail-pieee are alone employed in swimming. These segments are eurved from above downwards and eonfer on the posterior half of the body its eharacteristie eurved eontour (Plate eliv., Fig. 1, A, B, C, D, E).

During the downwards and forwards effeetive strokes the abdominal or posterior segments present a deeply eoneave, strongly resisting surfaee to the water; during the upward, baekward, non-effeetive strokes they present a rounded convex, eomparatively non-resisting surfaee. The effeetive strokes are delivered with immense energy and rapidity, the tail-pieee eoming down with a sudden swoop. The non-effeetive strokes are delivered slowly and are comparatively feeble. The lobster swims in a series of eurves spasmodically. To increase still further the effieacy of the down or effeetive strokes, the tail-pieee during those aets is widely spread, and has its area nearly doubled. Everything is in favour of the down effective strokes—the eoneave surfaee having the advantage over the eonvex one, the high speed over the low speed, and the large area over the small area.

The movements made by the abdominal segments, and the spreading and closing of the tail-pieee during the effeetive and non-effeetive strokes, will be readily understood by a referenee to Plate eliv., Figs. 2, 3, 4, and 5.

The abdominal segments of the lobster form a sort of movable armour. The remarkable eonfiguration referred to is oeeasioned by the posterior portions of the segments being large enough to admit the anterior portions of the segments next to them. This gives rise to a limited teleseoping or imbrieating of the segments within eaeh other; an arrangement whieh admits of very free downward movements of the segments, but effeetually prevents lateral movements, and upward movements, beyond eertain points. It follows, that the upward movements are limited, and lateral movements prevented. The downward movements are comparatively unlimited.

The effeet of the imbrieation is, that the anterior part of each segment, when the animal eurves and uneurves its body, glides baekwards and forwards within the posterior part of the segment beyond it, or nearer the head. This arrangement admits of very free eurvilinear movements, espeeially from above downwards.

The lobster, in swimming, ean eause the posterior part of its body and tail-pieee to eurve to the extent of three-quarters of a cirele. The parts named ean also be made to fold and double upon eaeh other. The folding movement is best seen when the effeetive stroke has just been delivered, and the animal is darting forwards tail first (Plate eliv., Fig. 1, E).

The movements of the abdominal or posterior segments and of the telson or tail-segment and tail-piece of the lobster are so free that the animal eould, if it ehose, apply the tail-pieee to the water as a fish applies its tail to that element. If it did, the lobster would strike from above downwards, as in the whale, porpoise, dugong, manatee, &c.; the fish (the flat fishes excepted) striking laterally.

The loose imbricating eurved arrangement to which attention has been direeted enables the lobster, in rapid swimming, to strike the water with tremendous energy in a direction from above downwards and forwards with the posterior part of its body and tail-pieee; the powerful muscles of the posterior segments and tail-piece being expressly designed to give a sudden down stroke; this being the stroke on whieh the lobster mainly relies for progress in swimming.

The stroke from below upwards is comparatively slow and feeble, and, being limited above, is ineffective, and plays quite a subordinate part in natation.

It only remains to say a few words regarding the tail-piece. This remarkable structure, which is hard and unyielding, is rounded and convex on its dorsal and upper surface, and scooped out and concave on its ventral or under surface. It is loosely jointed to the penultimate segment of the body, and consists of the following parts :—

(*a*) The telson, a tapering central portion ; the broad base being directed towards the head. This is jointed to the adjoining segment, and moves freely in an upward and downward direction but not laterally.

(*b*) Four flattened lateral plates, two superior and two inferior, hinged to the same segment. The bases of the lateral plates are directed away from the head, and the plates move very freely, not only vertically, but also laterally. A superior and inferior lateral plate occur on either side of the telson ; the inferior plates being divided transversely. The posterior margins of the parts forming the tail-piece are provided with a fringe of stiff hair-like processes which give a finished appearance. It is to the four conical-shaped lateral appendages that the tail-piece owes its power of nearly doubling its superficial area during the down or effective stroke in swimming.

The two inferior appendages have a wide range of lateral motion ; the lateral movements of the two superior ones being also free but more limited. The vertical movements of the several parts of the tail-piece are limited above but not below. The superior and inferior lateral plates when the tail-piece is expanded have a common spiral motion from above downwards. The spiral downward motion of the plates increases the concavity of the tail-piece during the down strokes.

As already indicated, the two inferior lateral plates are divided transversely and are hinged ; the hinge being so formed as to admit of a large amount of downward movement, but only a limited amount of upward movement.

The up strokes of the several parts of the tail-piece are restricted by four conical-shaped projections which extend from the dorsal surface of the last abdominal segment and cover the apices or roots of the two superior and two inferior lateral plates. A similar arrangement obtains on the dorsal surface of the abdominal segments where they imbricate.

The spreading out and expanding of the two superior and two inferior lateral appendages during the down effective strokes, and the bringing of them together during the up non-effective strokes, are analogous to similar movements occurring in the feet of swimming birds, and, indeed, in nearly everything which swims—the frog, fish, beaver, otter, platypus, walrus, seal, sea-lion, &c. The parts forming the tail-piece as drawn from nature (fresh specimen) are accurately depicted at Figs. 2, 3, 4, and 5 of Plate cliv., which see.

§ 363. The Swimming of the Fresh-water Tortoise.

The fresh-water tortoise (*Emys picta*) (Fig. 6, Plate cliv., p. 1161) is remarkable for its slow deliberate movements in and out of the water. It is an air breather, and when immersed rises ever and anon to the surface to respire. Its mode of swimming exactly resembles that of a man in walking, where the legs and arms move diagonally and swing alternately forward in space. The tortoise in swimming may be said to walk in the water ; its limbs and webbed feet acting diagonally in a *backward* direction, while the superior and inferior extremities of man act diagonally in a *forward* direction.

The limbs and webbed feet of the tortoise are specially adapted for swimming. They project from beneath the carapace ; the only parts seen from above being the two anterior and the two posterior extremities, which are directed backward as shown at Fig. 6 of Plate cliv. The limbs are turned in the direction in which they strike during the effective stroke.

I had favourable opportunities of studying the swimming of the fresh-water tortoise at Malaga, Spain, in 1901, and made out the following points which I transcribe from my note-book :—

1. The anterior and posterior extremities move diagonally and alternately.

2. The right anterior and the left posterior extremities move together or simultaneously. The left anterior and the right posterior extremities move in like manner.

3. The extremities in swimming are flexed or folded and moved slowly during the non-effective strokes ; they are extended and their movements quickened during the effective strokes.

4. The effective strokes are delivered in a *backward* direction.

5. The extremities while they are being flexed or folded during the forward non-effective strokes are also tilted obliquely to reduce the degree of friction experienced by them from the water. The opposite holds good during the backward effective strokes. In this case, the extremities are extended and present broad flat surfaces to the water.

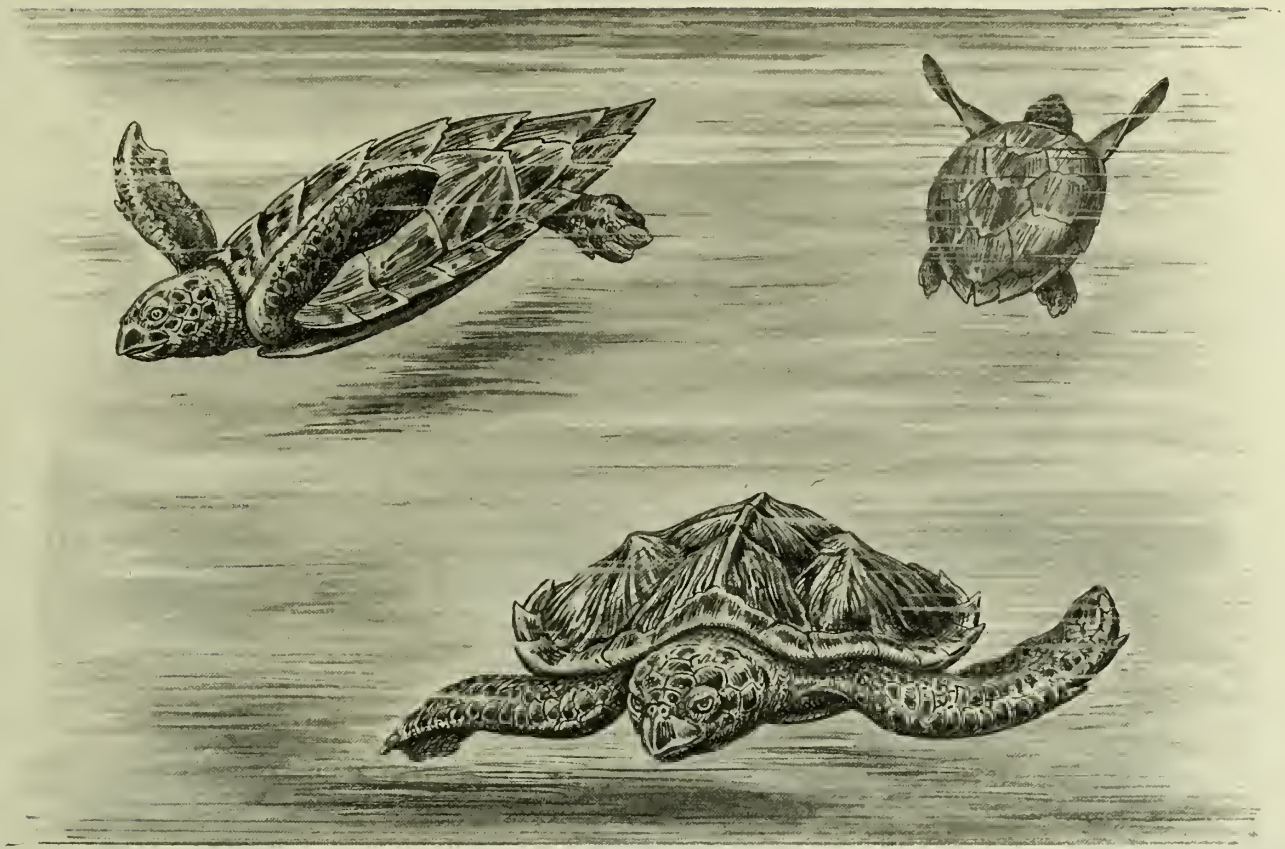


FIG. 499.—The hawk's-bill turtle (*Chelone imbricata*) (after Mützel).

6. The webbed feet of the tortoise are compressed during the forward non-effective strokes, and spread out during the backward effective ones.

7. The extremities during the non-effective strokes are drawn slowly towards the body and act as short levers. During the effective strokes, they are pushed suddenly away from the body and act as long levers.

8. The anterior and posterior extremities present convex surfaces to the water during the non-effective strokes, and concave ones during the effective strokes.

9. The anterior and posterior extremities describe ellipsoidal movements ; the outside of the ellipses corresponding with the effective strokes—the inside of the ellipses corresponding with the non-effective strokes.

10. The posterior extremities act in the same way as the feet of the duck and other water birds do, when swimming leisurely.

§ 364. The Swimming of the Turtle.

Similar remarks apply to the swimming of the hawk's-bill turtle (*Chelone imbricata*), which I have also been privileged to study in living specimens (see Figs. 5 and 6 of Plate cliv., p. 1161). This quaint animal has well developed typical flippers ; the two anterior ones being large triangular elastic structures which resemble true wings in that they are thick at the root and along the anterior margin, and thin at the tip and along the posterior margin. They are also slightly twisted upon themselves and form reciprocating screws (Fig. 499).

In swimming, the flippers of the turtle are applied to the water in pairs diagonally ; the anterior right and posterior left flipper moving together and alternating with the posterior right and anterior left flippers which also move simultaneously. The double diagonal movements are similar to those which, as stated, occur in man in walking.

§ 365. The Swimming of the Triton.

What is said of the movements of the feet and flippers of the fresh-water tortoise and hawk's-bill turtle is true of the movements of the extremities of the triton and crocodile when swimming, and of the feebly developed

corresponding members in the Lepidosiren, Proteus, and Axolotl, specimens of all of which are to be seen in the Zoological Society's Gardens, London. In all of these, natation is effected principally, if not altogether, by the tail and posterior half of the body, which is largely developed and flattened laterally for this purpose, as in the fish. The triton (Fig. 8, Plate cliii., p. 1148) is characteristic of the group.

§ 366. The Swimming of the Swan and other Birds.

The swimming of the bird, of which that of the swan is perhaps the best example, is interesting in many ways. It illustrates to perfection how the webbed foot when it makes the backward or effective stroke is expanded to the utmost, to secure the maximum of resistance, and how when it makes the forward or non-effective stroke it is neatly folded to reduce the resistance to a minimum. It shows, further, that the legs and feet move alternately; one leg and foot making the back effective stroke, while the other leg and foot make the forward non-effective one. Thus there is always one effective and one non-effective stroke being delivered, which ensures continuity of forward movement. The leg and foot making the effective stroke are always extended and more or less rigid; the leg and foot making the non-effective stroke being always flexed and more or less flaccid (Plate cliv., Fig. 7, A).

The foot which delivers the effective stroke makes a backward outward curve, that is, a curve with its convexity directed away from the mesial line of the bird; the foot which makes the non-effective stroke makes a forward inward curve, that is, a curve with its convexity directed towards the mesial line of the bird. The trajectory made by each foot of a swimming bird in the water is that of a double, reciprocal, figure-of-8 spiral, similar to what is produced by the body of a long-bodied fish when swimming leisurely (Plate cliv., Figs. 8 and 9).

The swimming of the bird is fairly smooth, because of the alternating complementary movements made by the two legs and feet, and the speed attained is, in some cases, very great, as, for example, in the steamer or race-horse duck, the cormorant, and great northern diver.

The swimming movements can be conveniently studied in public parks with ornamental waters, where large numbers of swans, geese, ducks, water-hens, coots, &c., are kept.

The swan, when swimming leisurely, develops the movements described above. When swimming hurriedly, this majestic bird causes both legs and feet to move synchronously or together; the back or effective stroke being delivered by both feet at the same instant—the same holding true of the feet during the forward or non-effective stroke. In rapid swimming, the swan advances spasmodically by a series of jerks. These points are illustrated at Plate cliv., Figs. 7, 8, and 9.

PLATE CLIV

Plate cliv. represents life studies by the Author of the swimming of the lobster, fresh-water tortoise, swimming bird, fish, &c., as drawn by C. Berjeau for the present work.

This plate shows how the swimming organs of the lobster, tortoise, bird, fish, &c., are opened out or expanded when the effective strokes are delivered, and folded or closed when the non-effective strokes are made; how the webbed feet of birds in swimming describe double figure-of-8 curves in the water, and how the body of the fish (especially the long-bodied fishes) is thrown into similar curves, particularly when swimming leisurely.

Fig. 1.—Carapace and abdominal or posterior segments of the lobster (*Homarus vulgaris*) drawn from the life. *a*, Carapace or shield; *b*, abdominal segments; *c*, *d*, *e*, *l*, telson or tail-segment with lateral appendages which are opened out during the effective strokes in swimming, and closed during the non-effective strokes; *f*, legs; *g*, swimmerets which act as paddles and assist in walking on the sea-bottom; the great propulsive organ being the tail-piece. When the lobster puts forth its greatest propulsive efforts it swims tail first by suddenly and violently curving its posterior segments and telson from above downwards, and forming a temporary bend or hook which seizes the water with tremendous energy.

A. *a*, *b*, *c*, Curve made by the abdominal segments and tail-piece of the lobster prior to making the vigorous downward and forward hooked movement which causes the animal to dart forward at incredible speed, tail first.

B. Curve made by the abdominal segments and tail-piece towards the end of the downward and forward stroke (see dotted outline of posterior portion of lobster, and darts indicating the direction of the stroke).

C. The downward stroke completed (*vide* dart); the abdominal segments and tail-piece forming a deeply concave surface directed forwards which seizes the water with great avidity and projects the body of the lobster tail first at immense speed.

D. The abdominal segments and tail-piece diminishing the concave surface and folding upon each other (see dart) to reduce the degree of friction in the line of advance.

E. The abdominal segments and tail-piece closely folded together—friction reduced to a minimum—the lobster darting forwards at a high speed, tail first, as indicated by the two arrows.

F. Section of one of the segments with swimmerets (r') attached. *m*, Dorsal surface of segment; *n*, dorsal ventral surface; *o*, projection and joint for modified limb (*p*); r', swimmerets with fringed margins which act as paddles and assist the lobster in walking on the sea bottom, head first.

Fig. 2.—Dorsal convex surface of the telson with the two outer lateral appendages approximated and placed beneath the two inner ones. *a*, Abdominal segment showing its anterior portion (a') which imbricates and moves within the posterior portion of

PLATE CLIV

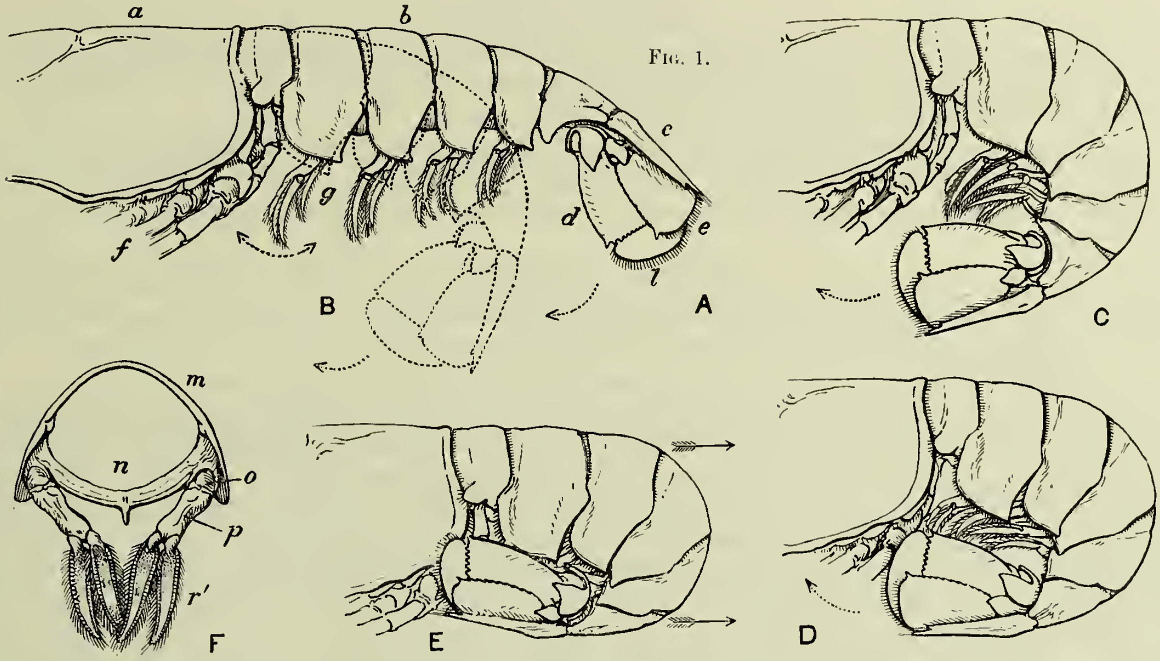
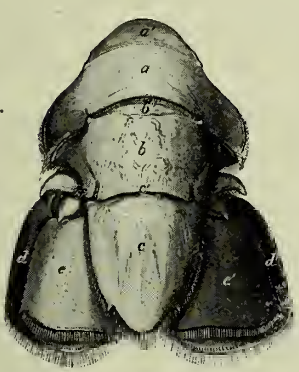


Fig. 1.

Fig. 2.



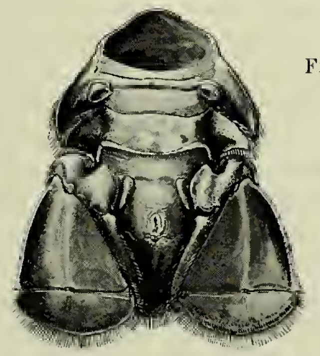


Fig. 3.

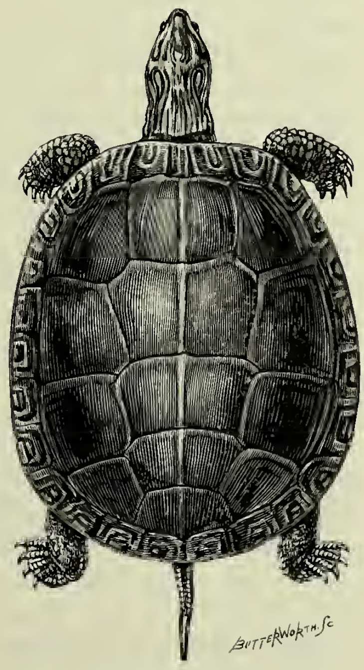
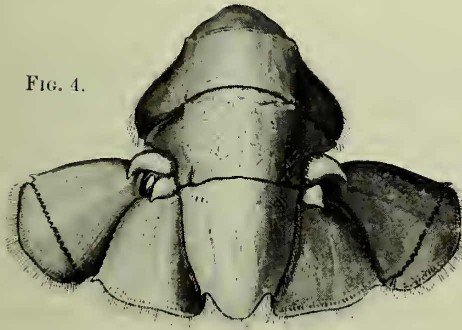


Fig. 6.

Fig. 4.



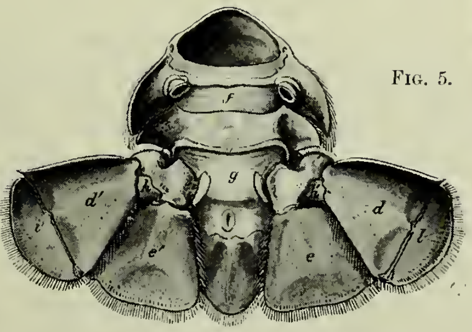


Fig. 5.

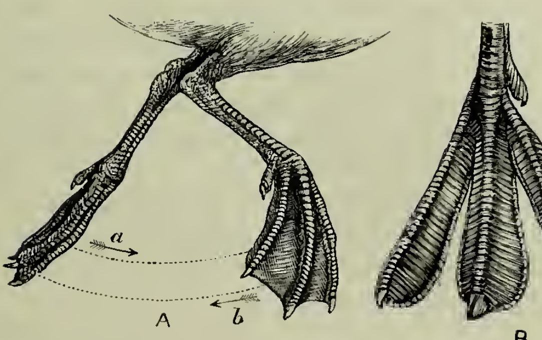


Fig. 7.

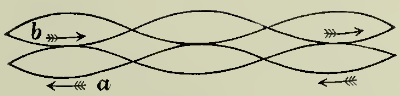


Fig. 8.

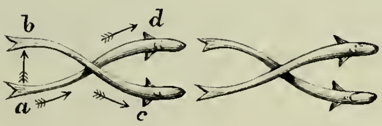


Fig. 9.

PLATE CLIV (*continued*)

the preceding abdominal segment ; *b*, nineteenth segment with part (*b'*) imbricating with eighteenth segment ; *c*, telson jointed to nineteenth segment ; *d*, *d'*, the two outer appendages placed beneath the two inner ones (*e*, *e'*). The outer appendages are hinged and spread out to the utmost during the effective stroke (see Fig. 4).

FIG. 3.—Ventral concave surface of the telson or tail-piece with its two outer conical-shaped jointed plates compressed and overlapping the two inner ones. Figs. 2 and 3 give the area of the tail-piece during the up or non-effective stroke.

FIG. 4.—The dorsal convex surface of the telson with the four flattened plates spread out to the utmost, as in the down effective stroke.

FIG. 5.—The ventral concave surface of the tail-piece fully expanded as in the effective stroke ; the swimming surface being greatly increased (compare with Fig. 3). The concave surface has a resistance of something like two to one against the convex surface. *d*, *d'*, The two outer appendages, each with a jointed portion (*l*, *l'*) ; *e*, *e'*, the two inner appendages. As already stated, the two outer plates are covered by the two inner ones during the non-effective stroke.

FIG. 6.—The fresh-water tortoise (*Emys picta*) with its feet webbed and limbs adapted for swimming.

The anterior and posterior limbs are directed backwards, the direction in which they deliver the effective strokes in natation. The anterior limbs somewhat resemble those of the turtle, which, however, are more highly differentiated swimming organs. Similar remarks apply to the posterior limbs of the turtle. The limbs and feet of the tortoise, in swimming, are made to move diagonally and alternately in pairs. Thus the left anterior limb and foot and the right posterior limb and foot move together or simultaneously ; the right anterior limb and foot and the left posterior limb and foot doing the same. The tortoise moves in the water very much as a man moves on *terra firma* ; it seems to walk in the water. The limbs and feet of the tortoise, in swimming, strike backwards during the effective strokes, in which case they act as long levers, and present concave surfaces to the water—the webbed feet being expanded to the utmost. During the non-effective strokes, the limbs and feet act as short levers, and present convex surfaces to the water—the webbed feet being compressed and their area diminished. Similar arrangements obtain in the webbed feet of swimming birds (after Cuvier : the movements described by the Author).

FIG. 7.—A. The feet of the swan in the act of swimming, the right foot fully expanded, and about to give the effective stroke, which is delivered outwards, downwards, and backwards, as represented at *b* ; the left foot being closed, and about to make the return stroke, which is delivered in a forward, upward, and inward direction, as shown at *a*. The feet are moved alternately and are slightly rotated on their long axis, or tilted, both during the effective and non-effective strokes ; and as they always move in curves, their course is accurately represented by a double spiral, as shown at Fig. 8. Compare the spirals formed by the feet of the bird in swimming with those described by the fish, and by man in walking.

In rapid swimming the legs and feet of the swan are not moved alternately but simultaneously ; in other words, the two legs are flexed and the two feet compressed and advanced slowly as short levers with convex surfaces during the non-effective strokes, whereas during the effective strokes the two legs are extended, the two feet spread out, and made to strike backwards quickly as long levers with concave surfaces. The difference between the effective and non-effective strokes is well marked, and the bird is seen to be urged forwards by a series of spasmodic jerks. (Drawn by C. Berjeau from nature for the Author.)

B. The foot of the grebe (*Podiceps*). In this foot each toe is provided with a web or swimming membrane ; the membranes being closed when the foot is flexed and giving the non-effective stroke, and spread ont when the foot is extended and delivering the effective stroke. In the swan, and most swimming birds, the web is continuous between the toes (after Dallas).

FIG. 8.—Double spiral trajectory made by the feet of the swan and other birds in swimming. When the right foot is describing the *outside* of a curve from before backwards, and from within outwards, as represented by the arrows (*a*) during the effective stroke, the left foot is describing the *inside* of a similar curve (*vide* arrows *b*), from behind forwards, and from without inwards, in the non-effective back stroke. The feet thus co-ordinate each other ; and as they reciprocate and alternate, the double spiral figure is obtained (the Author, 1867).

FIG. 9.—Diagram showing the course described by the fish in swimming. The fish, in swimming, contrary to the received opinion, throws itself into a double curve (*a*, *d*) ; the curves taking hold of the water and letting go or relieving each other alternately. When the tail is delivering the effective stroke, as indicated by the arrow running in the direction of *b*, the anterior portion of the fish (*d*) is reversing, as shown at *c*. These changes are effected with such rapidity that the fish appears to be in two places at the same instant ; and hence the double track figured. While the double curve is being formed, the fish is rotating upon its axis ; so that it is literally screwing itself forward in two directions, from side to side and from behind forwards (the Author, 1867).

§ 367. Analysis of the Swimming of the Fish.

According to Borelli,[1] and all who have written since his time, the fish in swimming causes its tail to vibrate on either side of a given line, very much as a rudder may be made to oscillate by moving its tiller. The line referred to corresponds to the axis of the fish when it is at rest and when its body is straight, and to the path pursued by the fish when it is swimming. It consequently represents the axis of the fish and the axis of motion. According to this theory the tail, when flexed or curved to make what is termed the back or non-effective stroke, is forced away from an imaginary line, its curved, concave, or biting surface being directed outwards. When, on the other hand, the tail is extended to make what is termed the effective or forward stroke, it is urged towards an imaginary line, its convex or non-biting surface being directed inwards (Fig. 500).

When the tail strikes in the direction *a*, *i*, the head of the fish is said to travel in the direction *c*, *h*. When

[1] Borelli, "De motu Animalium," Plate iv., Fig. 5, sm. 4to, 2 vols. Romæ, 1680.

the tail strikes in the direction *g*, *e*, the head is said to travel in the direction *c*, *b*; these movements, when the tail is urged with sufficient velocity, causing the body of the fish to move in the line *d*, *c*, *f*. The explanation is apparently a satisfactory one; but a careful analysis of the swimming of the living fish induces me to believe it to be incorrect. According to this, the commonly received view, the tail would experience a greater degree of resistance during the back stroke, that is, when it is flexed, curved, and carried away from the axis of motion (*d*, *c*, *f*) than it would during the forward stroke, or when it is extended, straightened, and carried towards the axis of motion. This follows, because the concave surface of the tail is applied comparatively slowly to the water during what is termed the back or non-effective stroke, and the convex surface is applied vigorously during what is termed the forward or effective stroke. This is just the opposite of what actually happens, and led Sir John Lubbock (Lord Avebury) to declare that there was a period in which the action of the tail dragged the fish backwards, which, of course, is erroneous. There is this further difficulty. When the tail of the fish is urged in the direction *g*, *e*, the head does not move in the direction *c*, *b* as stated, but in the direction *c*, *h*, the body of the fish describing the arc of a circle, *a*, *c*, *h*. This is a matter of observation. If a fish, when resting, suddenly forces its tail to one side and curves its body, the fish describes a curve in the water corresponding to that described by the body. If the concavity of the curve formed by the body is directed to the right side, the fish swims in a curve towards that side. To this there is no exception, as any one may readily satisfy himself, by watching the movements of gold fish in a vase. Observation and experiment have convinced me that when a fish swims it never throws its body into a single curve, as represented at Fig. 500, but always into a double or figure-of-8 curve, as shown at Fig. 501.[1]

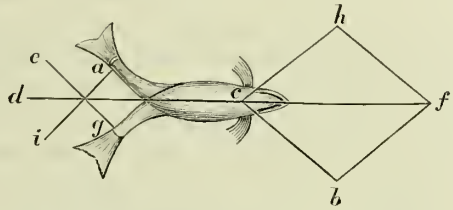


Fig. 500.—Swimming of the fish according to Borelli.

The double curve is necessary to enable the fish to present a convex or non-biting surface (*c*) to the water during flexion (the back stroke of authors), when the tail is being forced away from the axis of motion (*a*, *b*), and a concave or biting surface (*s*) during extension (the forward or effective stroke of authors), when the tail is being forced with increased energy towards the axis of motion (*a*, *b*); the resistance occasioned by a concave surface, when compared with a convex one, being in the ratio of two to one. The double or complementary curve into which the fish forces its body when swimming is necessary to correct the tendency which the head of the fish has to move in the same direction, or to the same side, as that towards which the tail curves. In swimming, the body of the fish describes a waved track, but this can only be done when the head and tail travel in opposite directions, and on opposite sides of a given line. The anterior and posterior portions of the fish alternately occupy the positions indicated at *d*, *c* and *w*, *v*; the fish oscillating on either side of a given line, and gliding along by a sinuous or wave-movement.

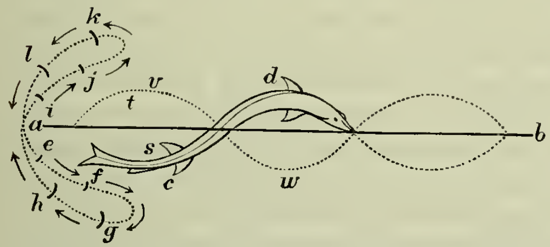


Fig. 501.—Swimming of the fish (sturgeon—*Acipenser sturio*) according to the Author. *a*, *b*, Line of advance; *c*, *d*, double or figure-of-8 curve made by the posterior (*c*) and anterior (*d*) halves of the body—the complementary curve being indicated at *v*, *w*; *e*, *f*, *g*, *h*, *i*, *j*, *k*, *l*, figure-of-8 trajectory made by the lateral oscillations of the tail, first in one direction (*s*) and then in another (*t*)—the larger cross curves (*g h*, *k l*,) on the figure-of-8 representing the most effective parts of the strokes; the smaller cross curves (*e f*, *i j*,) representing the least effective parts of the strokes. (Drawn from nature by the Author, 1867.)

I have represented the body of the fish as forced into two curves when swimming, as there are never less than two. These I designate the cephalic (*d*) and caudal (*c*) curves, from their respective positions. In the long-bodied fishes, such as the eels, the number of the curves is increased, but in every case the curves occur in pairs, and are complementary. The cephalic and caudal curves not only complement each other, but they act as fulcra for each other, the cephalic curve, with the water seized by it, forming the *point d'appui* for the caudal one, and *vice versâ*. The fish in swimming lashes its tail from side to side, precisely as an oar is lashed from side to side in sculling. It therefore describes a figure-of-8 track in the water (*e*, *f*, *g*, *h*, *i*, *j*, *k*, *l*, of Fig. 501). During each sweep or lateral movement the tail is both extended and flexed. It is extended and its curve reduced when it approaches the line *a*, *b*, and flexed, and a new curve formed, when it recedes from the line in question. The tail is effective as a propeller both during flexion and extension, so that, strictly speaking, the tail has no back or non-effective stroke. The terms effective and non-effective employed by authors are applicable only in a comparative and restricted sense; the tail always operating, but being a less effective propeller, when in the act of being flexed or curved, than when in the act of being extended or straightened. By always directing the concavity of the tail (*s* and *t*) towards the axis of motion (*a*, *b*) during extension, and its convexity (*c* and *v*) away from the axis of motion (*a*, *b*) during

[1] It is only when a fish is turning that it forces its body into a single curve.

flexion, the fish exerts a maximum of propelling power with a minimum of slip. In extension of the tail the caudal curve (s) is reduced as the tail travels *towards* the line a, b. In flexion a new curve (v) is formed as the tail travels *from* the line a, b. While the tail travels from s in the direction t, the head travels from d in the direction w. There is therefore a period, momentary it must be, when both the cephalic and caudal curves are reduced, and the body of the fish is straight, and free to advance without impediment. The different degrees of resistance experienced by the tail in describing its figure-of-8 movements, are represented by the different-sized curves e f, g h, i j, and k l, of Fig. 501. The curves e, f indicate the degree of resistance experienced by the tail during flexion, when it is being carried away from and to the right of the line a, b. The curves g, h indicate the resistance experienced by the tail when it is extended and carried towards the line a, b. This constitutes a half vibration or oscillation of the tail. The curves i, j indicate the resistance experienced by the tail when it is a second time flexed and carried away from the line a, b. The curves k, l indicate the amount of resistance experienced by the tail when it is a second time extended and carried towards the line a, b. This constitutes the remaining half of one complete vibration. These movements are repeated in rapid succession so long as the fish continues to swim forwards. They are only varied when the fish wishes to turn round, in which case the tail gives single strokes either to the right or left, according as it wishes to go to the right or left side respectively. The resistance experienced by the tail when in the positions indicated by e, f and i, j is diminished by the tail being slightly compressed, by its being moved more slowly, and by the fish rotating on its long axis so as to present the tail obliquely to the water. The resistance experienced by the tail when in the positions indicated by g, h, k, l, is increased by the tail being divaricated, by its being moved with increased energy, and by the fish re-rotating on its long axis, so as to present the flat of the tail to the water. The movements of the tail are slowed when the tail is carried away from the line a, b, and quickened when the tail is forced towards it. Nor is this all. When the tail is moved slowly away from the line a, b, it draws a current after it, which, being met by the tail when it is urged with increased velocity towards the line a, b, enormously increases the hold which the tail takes of the water, and consequently its propelling power. The tail may be said to work without slip, and to produce the precise kind of liquid currents which afford it the greatest leverage. In this respect the tail of the fish is infinitely superior as a propelling organ to any form of screw propeller yet devised. The screw at present employed in navigation ceases to be effective when propelled beyond a given speed. The screw formed by the tail of the fish, in virtue of its reversing reciprocating action, and the manner in which it alternately eludes and seizes the water, becomes more effective in proportion to the rapidity with which it is made to vibrate. The remarks now made of the tail and the water are equally *à propos* of the wing and the air. The tail and the wing act on a common principle. A certain analogy may therefore be traced between the water and air as media, and between the tail and wing as instruments of locomotion. From this it follows that the water and air are acted upon by curves or wave-pressure emanating in the one instance from the tail of the fish, and in the other from the wing of the insect, bat, or bird. The reciprocating and opposite curves into which the tail and wing are thrown in swimming and flying constitute *mobile helices* or *screws*, which, during their action, produce the precise kind and degree of pressure adapted to fluid media, and to which they respond with the greatest readiness. The whole body of the fish is thrown into action in swimming; but as the tail and posterior half of the trunk are more free to move than the head and anterior half, which are more rigid, and because the tendons of many of the trunk-muscles are inserted into the tail, the oscillation is greatest in the direction of the latter. The muscular movements travel in spiral waves from before backwards; and the waves of force react upon the water, and cause the fish to glide forwards in a series of curves. Since the head and tail, as has been stated, always travel in opposite directions, and the fish is constantly alternating or changing sides, it in reality describes a waved track. These remarks may be readily verified by a reference to the swimming of the sturgeon, the movements of which are unusually deliberate and slow. The number of curves into which the body of the fish is thrown in swimming is increased in the long-bodied fishes, as the eels, and decreased in those whose bodies are short or are comparatively devoid of flexibility. In proportion as the curves into which the body is thrown in swimming are diminished, the degree of rotation at the tail or in the fins is augmented, some fishes, as the mackerel, using the tail very much after the manner of a screw in a steamship. The fish may thus be said to drill the water in two directions, namely, from behind forwards by a twisting or screwing of the body on its long axis, and from side to side by causing its anterior and posterior portions to assume opposite curves. The pectoral and other fins are also thrown into curves when in action, the movement, as in the body itself, travelling in spiral waves; and it is worthy of remark that the wing of the insect, bat, and bird obeys similar impulses, the pinion, as I shall show further on, being essentially a spiral organ.

The twisting of the pectoral fins is well seen in the common perch (*Perca fluviatilis*), and still better in the 15-spined stickleback (*Gasterosteus spinachia*), which latter frequently progresses by their aid alone.[1] In the stickle-

[1] The *Syngnathi*, or pipefishes, swim chiefly by the undulating movement of the dorsal fin.

back, the pectoral fins are so delicate, and are plied with such velocity, that the eye is apt to overlook them, particularly when in motion. The action of the fins can be reversed at pleasure, so that it is by no means an unusual thing to see the stickleback progressing tail first. The fins are rotated or twisted, and their free margins lashed about by spiral movements which closely resemble those by which the wings of insects are propelled.[1] The rotating of the fish upon its long axis is seen to advantage in the shark and sturgeon, the former of which requires to turn on its side before it can seize its prey,—and likewise in the pipefish, the motions of which are unwontedly sluggish. The twisting of the tail is occasionally well marked in the swimming of the salamander.

The foregoing account of the swimming of the fish was written by me as early as 1867,[2] and I have frequently verified its accuracy.

So recently as March, 1904, at the aquarium of Naples, I took notes and made drawings of the movements made by the tails and pectoral fins of several fishes whch are wholly confirmatory of my views already expressed. As the notes are short and the drawings simple, I crave the indulgence of the reader for inserting them here. They are as follows : The tails of fishes when made to oscillate from side to side always develop double or figure-of-8 curves. When the tail is moved from right to left, the posterior free margin of the caudal fin makes the double curve indicated at A of Fig. 502. When the tail is moved from left to right the posterior free margin of the caudal fin makes the double curve indicated at B of Fig. 502.

These figures when placed together or united give the figure-of-8 shown at C.

When the tail is made to oscillate from side to side, it alternately spreads out and partially closes during each stroke. Thus when the tail is urged from right to left, it is spread out and makes a large curve at the beginning of the stroke—the curve being diminished and reversed towards the end of the stroke. The concavity of the large curve is directed towards the mesial line of the fish ; the convexity of the small curve being directed away from the said line.

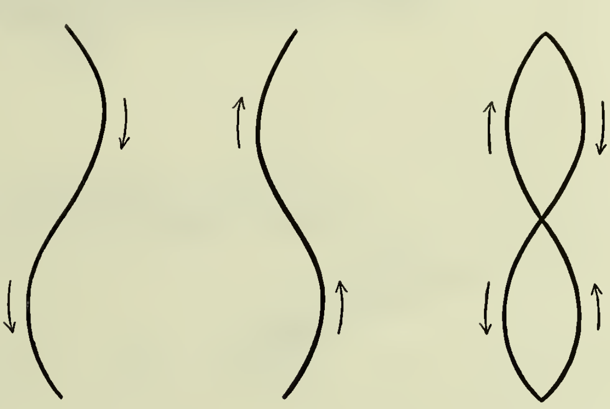


FIG. 502.—Double or figure-of-8 curves made by the tails and pectoral fins of fishes in swimming (the Author).

When the tail is urged from left to right, similar but opposite curves are developed. The curves made by the tail enable the fish to seize and let go the water in which it is immersed with surprising dexterity and ease, and in such a manner as to secure a maximum of propelling power with a minimum of slip.

What is said of the tail of the fish applies, as a rule, to the pectoral fins. These, in the majority of cases, develop double or figure-of-8 curves in all respects analogous to those witnessed in the tail. The pectoral fins generally move at the same time or synchronously. There are, however, cases in which they are moved separately and independently.

The pectoral fins are chiefly employed in ascending, descending, and balancing ; the great organ of propulsion being the tail.

The peculiarities of fishes as regards shape, size of fins, osseous and muscular arrangements, &c., are given at Plates clv., clvi., and clvii., which follow.

PLATE CLV

Plate clv. illustrates peculiarities in the general shape, and in the size and form of the fins of ancient and modern fishes.

FIG. 1.—Shark (*Cestracion galateus:* Australia). Exhibits old world peculiarities. The fins are comparatively very large, and the tail is unsymmetrical or heterocercal. There are two dorsal fins with a spike in front of each; two pectoral fins ; two ventral, an anal, and a caudal fin, all large and powerful. The sharks possess prodigious swimming power both as regards speed and endurance (after Günther).

[1] If the pectoral fins are to be regarded as the homologues of the anterior extremities (which they unquestionably are), it is not surprising that in them the spiral rotatory movements which are traceable in the extremities of quadrupeds, and so fully developed in the wings of bats and birds, should be clearly foreshadowed. "The muscles of the pectoral fins," remarks Professor Owen, "though, when compared with those of the homologous members in higher vertebrates, they are very small, few, and simple, yet suffice for all the requisite movements of the fins—elevating, depressing, advancing, and again laying them prone and flat, by an oblique stroke, upon the sides of the body. The rays or digits of both pectorals and ventrals (the homologues of the posterior extremities) can be divaricated and approximated, and the intervening webs spread out or folded up."

[2] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom." (*Trans. Linn. Soc.*, vol. xxvi.)

PLATE CLV

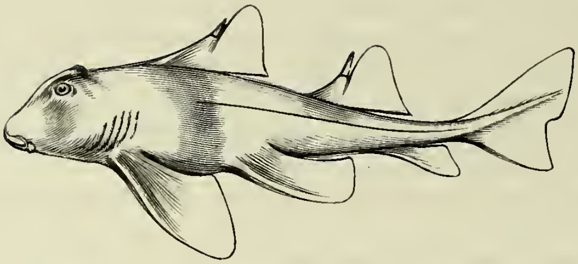


Fig. 1.

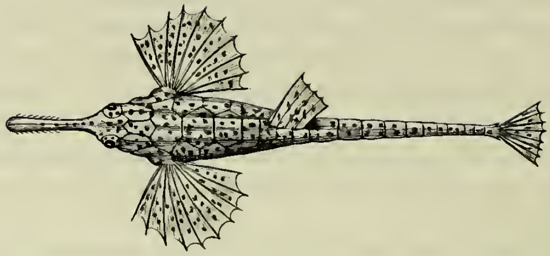


Fig. 2.

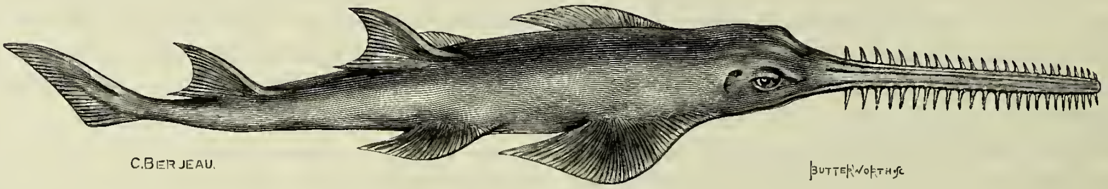


Fig. 3.

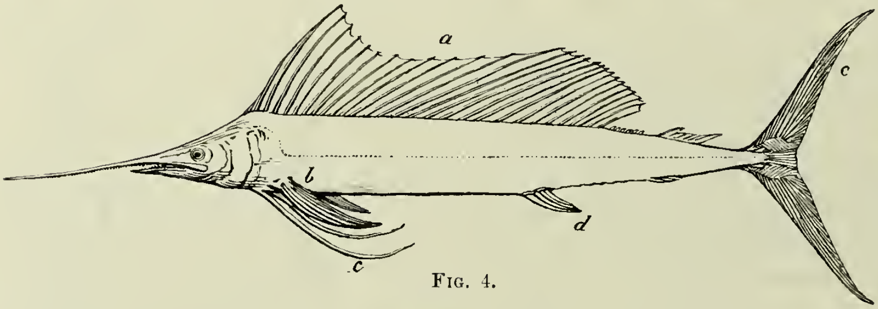


Fig. 4.

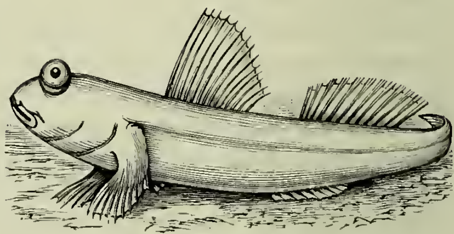


Fig. 5.

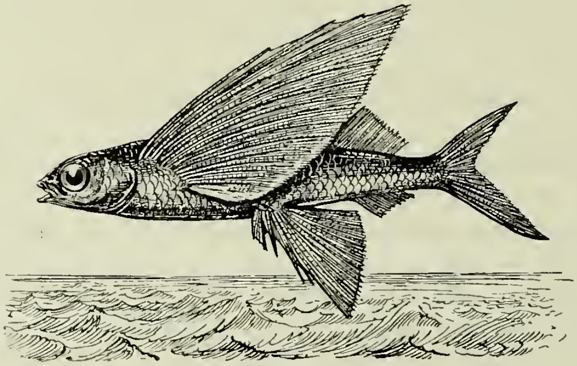


Fig. 7.

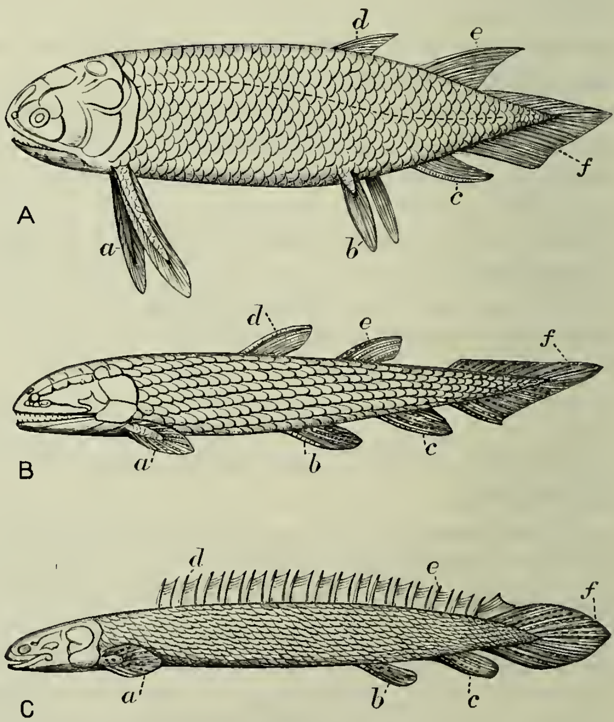


Fig. 6.

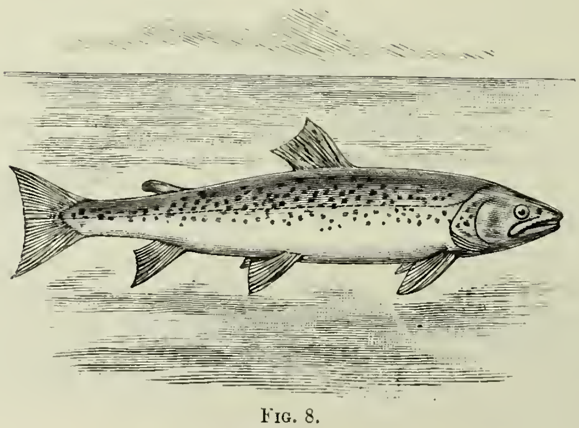


Fig. 8.

PLATE CLV (*continued*)

FIG. 2.—*Pegasus natans:* China and Australia. A curious little fish, the body of which is covered with bony plates. The fins consist of two pectorals, one dorsal, one ventral, one anal, and one caudal. The pectoral fins are very large, of a triangular rounded shape and radiate like fans. They bear a general resemblance to certain wings, and, as they can generate spiral wave-movements, are very useful not only in swimming but in elevating or depressing the body of the fish (after Günther).

FIG. 3.—The saw-fish (*Pristis:* tropical and sub-tropical). A remarkable old world form. Has large powerful fins and unsymmetrical heterocercal tail like the shark (Fig. 1). The outstanding feature is the saw, which sometimes measures six feet in length and is a most formidable weapon of attack. It has two large pectoral and two large ventral fins; the rays of the pectoral fins radiating like those of the common skate (*Raja batis*). The dorsal fins are triangular in shape, with thick, tapering, semi-rigid anterior margins, and thin, tapering, posterior margins, in which respects they resemble true wings. The caudal or tail fin, which is fleshy and heterocercal, has the same general structure as the dorsal fins. The saw-fish is one of the most powerful swimmers known; a circumstance partly due to the large graduated, elastic, finely-shaped fins, but chiefly to the wonderful mobility possessed by the posterior half of the body which forms a long lever for the highly organised tail. (Drawn for the present work from nature by C. Berjeau.)

FIG. 4.—The sword-fish (*Histiophorus indicus:* tropical and sub-tropical) is one of the swiftest, most courageous, and dangerous of the fish tribe. It attains to 12 and 15 feet in length with sword measuring 3 feet and upwards. It fearlessly attacks whales and other large animals, and, occasionally, boats. Represents an old world type. The fins are remarkable, especially the dorsal fin (*a*), which is very ample and extends along the back quite two-thirds of the body. Its width in some parts exceeds the depth of the body, and, as its rays can be erected, it is said to act occasionally as a sail when the fish is floating at the surface of the water. The pectoral and anal fins (*b*, *d*) are small; the ventral ones (*c*) assuming the form of styliform appendages. The caudal or tail fin (*e*) is one of the most beautifully formed and perfect swimming organs in existence. It consists of two triangular symmetrical portions curiously tied together at their roots; each portion resembling the wing of a swift. The rays of each half of the tail radiate and taper outwards and backwards; the tail being thickest at the root and along the anterior margin, and thinnest at the free extremities and along the posterior margin: it is also highly elastic, in all which it possesses the true wing structure. The outstanding features are the great spread and narrowness of the tail, which secure greatly increased leverage and smooth rapid working. It has only to be added that the posterior third of the body of the sword-fish forms a long, tapering, highly flexible lever which confers on the tail every possible mechanical advantage. The tail of the sword-fish resembles in a general way that of the mackerel (*Scomber scomber*), but it is more highly differentiated as a swimming organ. (Drawn for the present work from nature by C. Berjeau.)

FIG. 5.—Goby or "walking-fish" (*Periophthalmus koelreuteri:* tropical and temperate). This remarkable fish is provided with two large dorsal fins, and two muscular pectoral fins, which, with the coalesced ventral fins and tail, it employs for walking and leaping on the mud from which the tide has receded. It hobbles along with great celerity in search of small crustaceans upon which it largely lives. To its other peculiarities it adds large movable eyes which can be extruded from the head and enable it to see as well in air as in water. It also builds a nest for its eggs, which it jealously guards until they are hatched out. The goby, as its appearance indicates, is more or less an old world form. It shares its power of leaving the water for longer or shorter intervals with the eel (*Anguilla*), mud fish (*Amia calva*), climbing perch (*Anabas scandens*), &c. (after Günther).

FIG. 6.—(A, B, C). Represents three ganoid or old world fossil fishes which are, in several respects, peculiar. They are, so to speak, armour plated, and their fins are small and curiously shaped. Their semi-rigid casing of armour, coupled with their diminutive swimming organs, must have greatly impaired their powers of locomotion.

A. *Holoptychius nobilissimus*, a fossil form restored by Professor Huxley. Found in the Upper Old Red Sandstone at Dura Den, Cupar, Fife. Characterised by two narrow fringed pectoral fins (*a*), two smaller fringed ventral fins (*b*), one anal fin (*c*), two dorsal fins (*d*, *e*), and an aborted somewhat square-shaped heterocercal caudal or tail fin (*f*). Neither the size nor the shape of the fins gives indication of rapid swimming.

B. *Osteolepis*, as restored by Pander. Found in the Middle Old Red Sandstone. This fossil fish resembles that figured at A, but is of more slender build, and its caudal fin is more triangular in shape. Its general form and the greater size of its fins no doubt somewhat improved its swimming capacity. *a*, One of the fringed pectoral fins; *b*, one of the ventral fins; *c*, anal fin; *d*, *e*, dorsal fins; *f*, triangular-shaped heterocercal caudal or tail fin.

C. *Polypterus* (Agassiz), a fish of the ganoid type living in the Nile and other African rivers. It has a long slender body, and differs slightly from the ganoids figured at A and B, in the shape and position of its fins; more especially the dorsal and caudal fins. *a*, One of the fringed pectoral fins; *b*, one of the ventral fins; *c*, anal fin; *d*, *e*, dorsal fin composed of a series of separate finlets which resemble diminutive sails; *f*, oval-shaped radiating caudal or tail fin. The swimming powers of this and the other ganoids figured are, from the nature of things, limited, as compared with some other old world forms, especially the sharks, which, as has been explained, are amongst the swiftest of fishes.

FIG. 7.—The flying-fish (*Exocœtus:* tropical and sub-tropical). This curious and striking fish forms a transition or connecting link between locomotion in the water and in the air. It swims well in the water, and, at times, flies in the air parachute-fashion. To this end, it is provided with two very large pectoral fins which considerably resemble ordinary wings. By the vigorous action of its powerful tail in the water it acquires the momentum which enables it to shoot out of that medium and fly or glide in a parabolic curve for 500 or more feet. As all the fins of the flying-fish are large, the creature resembles a toy boat in full sail. (Drawn for the present work from nature by C. Berjeau.)

FIG. 8.—The sea-trout (*Salmo trutta*) affords an admirable example of a modern fish both as regards its shape and power of swimming. It is a handsome fish, and its fins, which are of moderate size, are well formed. Its caudal or tail-fin on which it relies chiefly for progression is triangular in shape. Its rays radiating from a central point, are carefully graduated and tapered, and are very elastic and mobile. The rays can also be separated and brought together when the tail is lashed from side to side by the lower half of the body. The tail and posterior half of the body work together and form a remarkably effective swimming organ. (Drawn for the present work from nature by C. Berjeau.)

PLATE CLVI

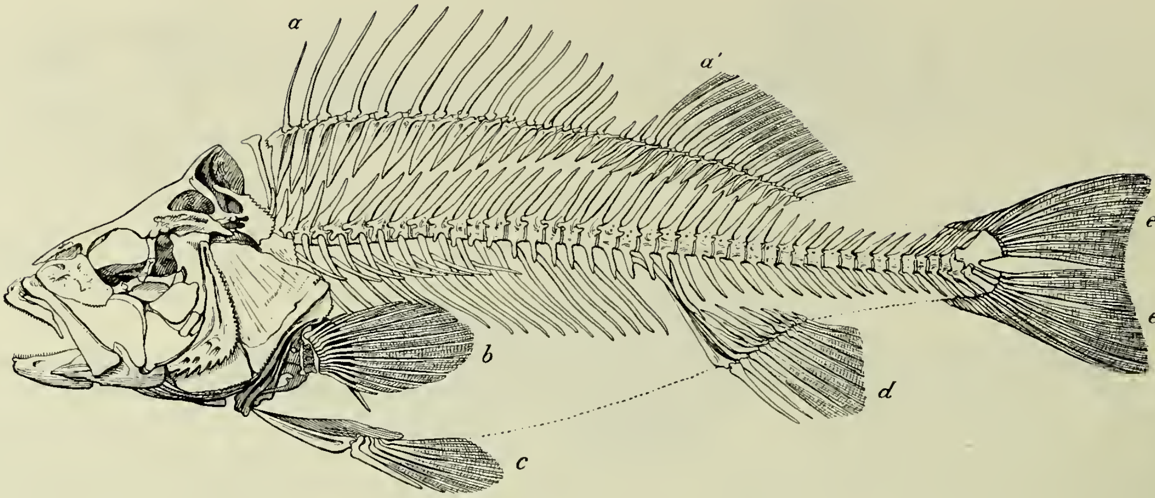


Fig. 1.

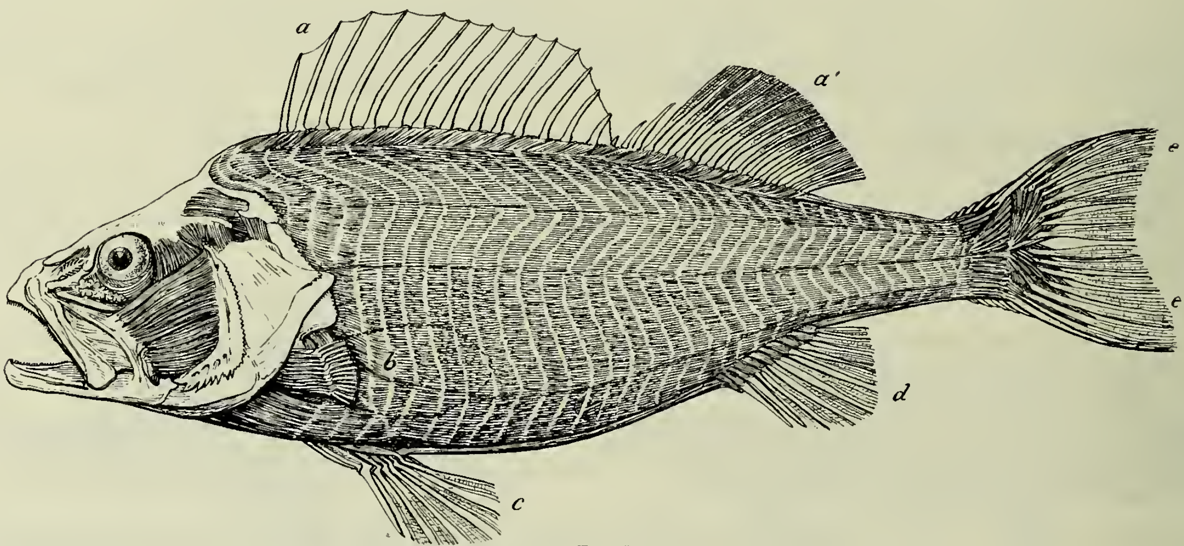


Fig. 2.

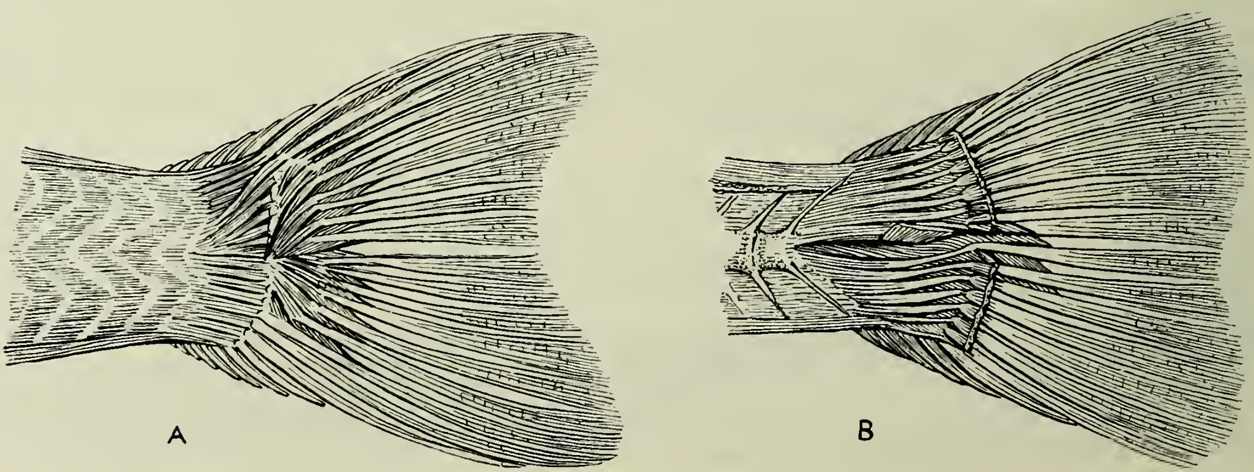


Fig. 3.

PLATE CLVI

Plate clvi. Shows the osseous, muscular, and other arrangements connected with the swimming of the perch (*Perca fluviatilis*). The spinal column and bones generally, as well as the muscles, are arranged to facilitate the lateral sinuous movements of the body and tail. The rays of the fins are specially devised to admit of opening and closing movements, so that the extent of the fins can be increased and diminished at pleasure. The opening and closing movements seen in all the fins are particularly observable in the caudal or tail fin which is divided into two portions.

FIG. 1.—Skeleton of the perch (*Perca fluviatilis*) (after Cuvier). The spinal column and its bony appendages occupy a central position in the body and are extended vertically so as to make the body thinner in this direction and allow of the lateral lashing of the body and tail in swimming. *a*, *a'*, Rays of dorsal fins, tapering, curved, elastic, and branching; *b*, rays of pectoral fin ditto; *c*, rays of ventral fin ditto; *d*, rays of anal fin ditto; *e*, *e'*, spines of caudal or tail fin which is divided into two triangular portions united at the root of the tail. The rays of all the fins are jointed at their bases of support so as to secure great freedom of movement in all directions, especially a divaricating or spreading movement and a closing or compressing movement. The arrangement of the bones and rays at the root of the tail is at once important and instructive. The tail consists of two triangular portions; the rays of each portion radiating in curves from the spinous processes of the last portions of the vertebral column to which they are united by joints. The rays of the caudal fin taper and branch and are highly elastic; the tail being thickest at its root and along its upper and lower margins, and thinnest at its posterior margin. The tail, structurally, is essentially a wing. An artificial fish tail can be readily constructed by lashing together two triangular-shaped wings at their roots to an elastic lever. Such artificial tail is a powerful propeller.

FIG. 2.—The muscular system of the perch (*Perca fluviatilis*). The muscles of the body and tail of the fish are arranged in two longitudinal sets (the great lateral muscles of Cuvier) which are each divided by a median longitudinal groove into a dorsal and ventral half. The two longitudinal sets are divided vertically into a number of flakes or segments (*myocommas*) by aponeurotic septa which supply points of attachment for the muscular fibres. The vertical divisions are zig-zagged across the body and occur at regular intervals. In addition to the two great lateral longitudinal muscles the fibres of which run from the head to the tail of the fish, there are other muscles the fibres of which pursue oblique directions. The longitudinal or straight muscles flex or curve and extend the body and tail in swimming; the oblique muscles twisting and rotating them; and the straight and oblique muscles, between them, producing spiral double curve figure-of-8 movements. When the lateral sinuous spiral movements are continued and run into each other they engender a double curve, figure-of-8 trajectory.

Similar movements occur in the several fins, especially the caudal and pectoral ones, the rays of the former separating when the effective strokes are being given, and coming together when the non-effective strokes are being made. The caudal and other fins are furnished with intrinsic muscles of their own, and the same is true of the different portions of the head. The muscles are attached to the several parts of the skeleton, and more particularly to the vertebral column and ribs. The muscular system may be said to centre in the vertebral column, and to this the chief s imming movements are to be traced. *a*, *a'*, Dorsal fins with transparent swimming membrane stretched between the rays; *b*, pectoral fin cut across; *c*, ventral fin; *d*, anal fin; *e*, *e'*, caudal or tail fin (after Cuvier).

FIG. 3.—Caudal fin or tail of the perch (*Perca fluviatilis*) in the expanded (A) and unexpanded (B) condition. Shows the straight and oblique muscles connected with the tail which bend or curve it, which cause it to twist and rotate slightly on its axis, which confer on it spiral figure-of-8 wave movements, and which separate and spread out its rays when the effective stroke is being delivered, and approximate and bring them together during the non-effective stroke.

A. In this figure the rays of the caudal fin are separated, and the swimming membrane between them put upon the stretch (superficial view).

B. In this figure the rays of the caudal fin are approximated, and the area of the tail diminished (deeper view).

In A and B the straight and oblique muscles (superficial and deep) going to the tail are well seen and fully account for the double curve spiral figure-of-8 movements made by it.

PLATE CLVII

Plate clvii. Illustrates how the rays of the symmetrical caudal or tail fin of the herring and mackerel are brought together and the area of the tail diminished, and how they are separated and the area of the tail increased. The same thing happens, although to a less extent, in the unsymmetrical or heterocercal tail of the shark and sturgeon, and in the webbed flippers and hind feet of the seal. This Plate also shows how the skate flies rather than swims through the water by means of its immense pectoral fins, how the pectoral fins and tail of the thresher shark are formed on a wing-model, and how, in one sense, these fins are to be regarded as flying, as well as swimming organs.

FIG. 1.—The herring (*Clupea harengus*: temperate zone). Shows the tail when most compressed.

FIG. 2.—The same with the tail moderately expanded.

FIG. 3.—The same with the tail fully expanded. (Drawn for the present work from nature by C. Berjeau.)

FIG. 4.—The mackerel (*Scomber scomber*: temperate and tropical seas). Shows the tail fully compressed.

FIG. 5.—The same with the tail fully expanded. The mackerel is a remarkably fast swimming fish; the shape of the body, and the size and form of the caudal fin contributing to this result. The activity of the fish is such that it is provided with darker

PLATE CLVII

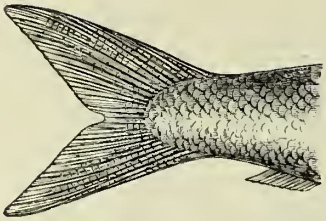
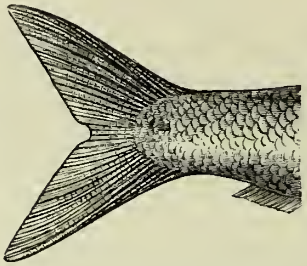


Fig. 1.



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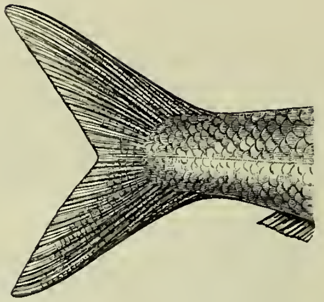


Fig. 3.

Fig. 6.

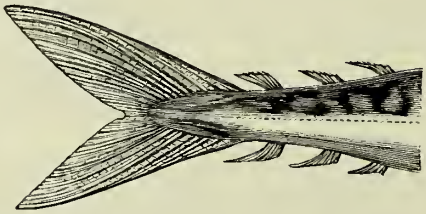


Fig. 4.

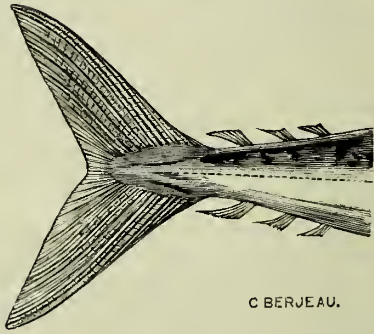


Fig. 5.

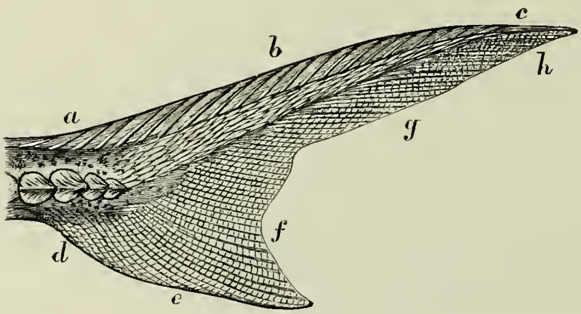


Fig. 7.

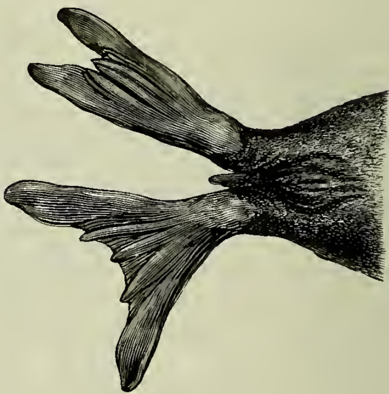


Fig. 8.

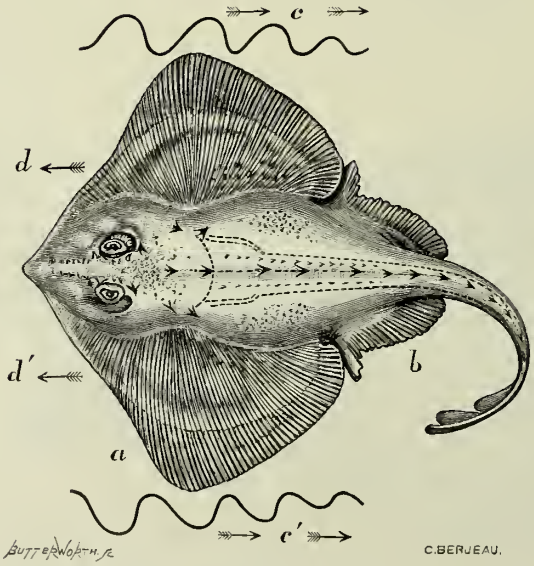


Fig. 9.

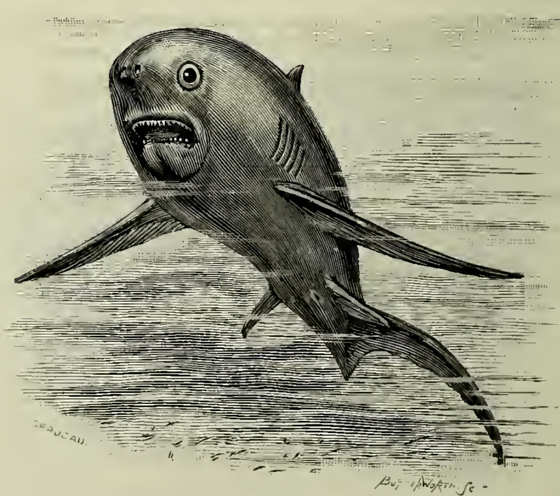


Fig. 10.

PLATE CLVII (*continued*)

muscles, a better blood supply, and a higher temperature than most other denizens of the sea. (Drawn for the present work from nature by C. Berjeau.)

Fig. 6.—The Greenland shark (*Læmargus borealis:* Arctic regions). The tail of this shark is unsymmetrical or heterocercal; the upper lobe in which the vertebral column terminates being the larger of the two lobes composing it. The tail tapers from its root upwards, downwards, and backwards, and its rays run in a horizontal, oblique, and downward direction. The rays divaricate very little, the organ deriving its power chiefly from its graduated structure, and the fact that it is highly elastic and flexible and is propelled by the posterior half of the body which forms a long and very effective lever. (Drawn from nature by the Author.)

Fig. 7.—The sturgeon (*Acipenser sturio:* temperate zone) is, perhaps, the geologically youngest of the ganoid fishes. The tail is unsymmetrical or heterocercal, and consists of an upper and lower portion. The spinal column terminates in the upper portion, which is the larger of the two. The tail tapers, and is beautifully graduated: the superior margin (*a*, *b*) being thicker than the inferior margin (*d*, *e*), and the root (*a*, *d*) being thicker than the posterior free margin (*f*, *g*, *h*). The rays radiate obliquely upwards and backwards, backwards, and downwards and backwards. The tail is a highly elastic springy organ, and, as it is lashed with great force from side to side by the posterior third of the body in swimming, it forms a most effective propeller. The tail of the sturgeon bears a general resemblance to that of the Greenland shark (Fig. 6) (after Gunther).

Fig. 8.—The elephant seal (*Macrorhinus leoninus:* South America, &c.). Shows the webbed hind flippers in the compressed or folded condition and in the fully expanded condition. The hind flippers of the seal correspond to the two halves of the tail of the fish as a swimming organ, and no better example can be given of the manner in which what is virtually the swimming tail of the seal is alternately opened up and closed during the effective and non-effective strokes. The five toes of each hind flipper correspond to the rays of each half of the fish tail, and the toes and the rays are alternately separated and brought together in precisely the same way by their appropriate muscles. Similar remarks apply to the hind flippers of the walrus and sea-lion. The anterior or fore flippers of the seal, sea-lion, and walrus are formed on the same plan as the hind ones and possess like powers. (Drawn for the present work by C. Berjeau.)

Fig. 9.—The common skate (*Raja batis:* temperate zone). Shows the radiating greatly expanded pectoral (*a*) and ventral (*b*) fins, by the aid of which the fish flies rather than swims through the water in a series of undulations (*c*, *c'*) which travelling backwards propel the body forwards (*d*, *d'*). (Drawn for the present work from nature by C. Berjeau.)

Fig. 10.—The thresher or fox shark (*Alopecias vulpes:* sub-tropical and temperate). Shows splendid pectoral fins and a huge scythe-like swimming tail. The pectoral and caudal fins are beautifully graduated and resemble wings, in that they are triangular in shape and exquisitely graduated; being thick at the root and along the upper anterior margin, and thin at the tip and along the lower posterior margin. They are highly flexible and elastic and endow their possessor with extraordinary swimming power. The arrangement and size of the fins enable this particular shark to roll over and seize its prey with precision and alacrity notwithstanding the awkward position of the mouth. (Photographed from nature for the Author by E. M.)

In the swimming of the fish the whole body is engaged; this being thrown into double reversing complementary curves well seen in the long-bodied fishes, such as the eels, certain sharks, and sturgeons. The posterior half of the body and the caudal fin or tail form a long and, consequently, powerful lever, and perform the chief part of the work. The swimming movements of the body and tail furnish examples of reciprocal sinuous wave movements; the posterior part of the body and tail being made to oscillate on either side of the trunk with immense speed and power, and in such a way as to secure the maximum of propelling power with the minimum of slip. While the sinuous movements are being developed, the fish is also rotating and twisting slightly on its long axis. The sinuous and semi-rotatory movements of the body are accompanied by remarkable changes in the tail itself. This finely formed and highly mobile organ develops at its free posterior margin spiral double curve figure-of-8 movements of its own. Similar movements appear in the fins, especially the pectoral ones. These movements in the body, tail, and fins can readily be detected even by the inexperienced observer. They are less apparent in the short bodied fishes than in the more elongated forms, but they occur in all.

The movements of the fish in swimming are at once peculiar, graceful, and striking. They follow each other, in many cases, with extreme rapidity, but there is nothing jerky or spasmodic in them. On the contrary, they are continuous gliding movements, which run into each other without hitch or impediment of any kind, and, occasionally, with lightning rapidity. Who has not seen a river trout dart through the clear water of a placid pool like a flash of light, not knowing whence it came or whither it went?

The movements of fishes can be best studied in fish ponds and in well stocked aquariums; but, failing these, all the main points can be readily made out by the judicious use of a vase of goldfish.

Before entering on an analysis of the swimming movements of the fish, it will be well to discuss with some little detail its muscular arrangements, as on these all the movements, simple and complex, primarily depend.

§ 368. Consideration of the Osseous and Muscular Systems of the Fish.

In order fully to comprehend the lateral sinuous double curve movements made by the body and tail of the fish in swimming, it is necessary to bear in mind that the skeleton of the fish, and especially the vertebral column, is specially constructed to facilitate *lateral* sinuous horizontal movements, and prevent *vertical* sinuous up and down

movements. The muscles, in like manner, are specially devised and arranged to throw the body and tail of the fish into opposite complemental curves and to confer on them a certain degree of spiral rotatory motion.

The fundamental idea in the muscular system of the fish is a system composed of longitudinal bands, the fibres of which run in the direction of the length of the body; the bands themselves occupying lateral positions and forming the sides of the fish. Such a system of muscles suffices to produce single curve movements of the body and tail, provided the two sets of longitudinal muscular bands work in unison; the one set contracting and shortening when the other is relaxing and elongating and *vice versâ*.

Such a simple arrangement actually obtains in the lowest vertebrate, the lancelet, where the muscular system consists of two longitudinal bands, one of which runs along each side of the body; the bands being divided vertically by aponeurotic septa into flakes or segments (*myocommas*) which give attachments to the muscular fibres. The longitudinal muscular bands form the prototypes of the "great lateral muscles" of Cuvier. The muscular bands have no connection with the notochord, unless in front, where there is a slight connection with the visceral skeleton.

Similarly, in the Cyclostomes the greater portion of the muscular system is not directly related to the skeleton, unless on the skull and visceral skeleton, where separate muscles are set apart for the performance of special functions.

In the higher fishes, the simple longitudinal lateral arrangement of muscles (which I regard as fundamental) persists, but other muscles make their appearance, which move the several parts of the head, the various fins, &c. The longitudinal muscles themselves are complex and are composed of many smaller segments corresponding with the number of the vertebræ.

Not only do the longitudinal lateral muscles become complex in structure, but muscles with varying degrees of obliquity are added; these having special attachments to the vertebral column and its appendages, to the ribs, to the tail, to the dorsal, pectoral, ventral, and anal fins, and wherever special movements are a desideratum.

The added muscles, and the additional complexity in the structure of the great longitudinal lateral muscles, fully meet the requirements of the case, and make the double curve spiral semi-rotatory movements of the body and tail and other fins, witnessed in the swimming of the higher fishes, possible.

When the surfaces of the two great longitudinal lateral muscles are examined, a median longitudinal groove is seen to divide each muscle into a dorsal and ventral half so as to produce what is virtually a four-fold arrangement of the muscles. The groove referred to contains blood-vessels and a considerable quantity of fat and embryonal muscular substance which is of a darker colour than the other muscles. It therefore forms a well-marked dividing line. The surfaces of the great longitudinal lateral muscles are further seen to be marked by white parallel zigzag stripes arranged vertically; the stripes being formed by aponeurotic septa occurring between the segments or myocommas, each aponeurotic septum being attached to the middle and the apophysis of a vertebra or to a rib where it exists. The aponeurotic septa, in many cases, receive additional supports from epipleural spines. The muscular fibres of the segments or myocommas follow a straight longitudinal course between the aponeurotic septa and are grouped to form conical masses; the dorsal and ventral conical masses having their apices directed backwards, and the central conical mass having its apex directed forwards. The two sets of cones mutually dovetail and interlock each other. As a consequence of this arrangement, the muscular system of the body of the higher fishes on transverse section is seen to consist of a longitudinal series of concentric rings symmetrically arranged in four groups equidistant from the spinal column.

The following is the account of the myology of the fish written by me in 1867:[1] "In the fish the muscles are for the most part arranged in dorsal, ventral, and lateral sets, which run longitudinally; and, as a result, the movements of the trunk, particularly towards the tail, are from side to side and sinuous. As, however, oblique fibres are also present, and the tendons of the longitudinal ones in some instances cross obliquely towards the tail, the fish has also the power of tilting or twisting its trunk (particularly the posterior half) as well as the caudal fin.

"In a mackerel which I dissected, the oblique muscles were represented by the four lateral masses occurring between the dorsal, ventral, and lateral longitudinal muscles—two of these being found on either side of the fish, and corresponding to the myocommas or '*grand muscle latéral*' (Cuvier). The muscular system of the fish would therefore seem to be arranged on a fourfold plan,—there being four sets of longitudinal muscles, and a corresponding number of slightly oblique and oblique muscles; the oblique muscles being spiral in their nature and tending to cross or intersect at various angles, an arrest of the intersection, as it appears to me, giving rise to the myocommas and to that concentric arrangement of their constituent parts so evident on transverse section. This disposition of the muscular fibres to cross each other at various degrees of obliquity may also be traced in several parts of the human body, as, for instance, in the deltoid muscle of the arm and the deep muscles of the leg. Numerous other examples

[1] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom." (*Trans. Linn. Soc.*, vol. xxvi. p. 201.)

of penniform muscles might be adduced. Although the fibres of the myocommas have a more or less longitudinal direction, the myocommas themselves pursue an oblique spiral course from before backwards and from within outwards, that is, from the spine towards the periphery, where they receive slightly oblique fibres from the longitudinal dorsal, ventral, and lateral muscles. As the spiral oblique myocommas and the oblique fibres from the longitudinal muscles act directly and indirectly upon the spines of the vertebræ, and the vertebræ themselves, to which they are specially adapted, and as both sets of oblique fibres are geared by interdigitations to the fourfold set of longitudinal muscles, the lateral, sinuous, and rotatory movements of the fish referred to are readily accounted for.

"The peculiar formation of the spinal column of the fish facilitates the lateral sinuous twisting movements of the tail and trunk, from the fact of the vertebræ composing it being united to each other by a series of modified universal joints—the vertebræ supplying the cup-shaped depressions or sockets, the intervertebral substance the prominence or ball.

"The same may be said of the general arrangement of the muscles in the trunk and tail of the cetacea, the principal muscles in this case being distributed, not on the sides, but on the dorsal and ventral aspects. The lashing of the tail in the whales is consequently from above downwards or vertically, instead of from side to side. The spinal column is jointed as in the fish, with this difference, that the vertebræ (especially towards the tail) form the rounded prominences or balls, the menisci or cup-shaped intervertebral plates the receptacles or sockets."

When limbs are present, the spine may be regarded as being ideally divided, the spiral movements, under these circumstances, being thrown upon the extremities by typical ball-and-socket joints occurring at the shoulder and pelvis. This is peculiarly the case in the seal, where the spirally sinuous movements of the spine in swimming are transferred directly to the posterior extremities.

The extremities, when present, are provided with their own muscular cycles of extensor and flexor, abductor and adductor, pronator and supinator muscles. These run longitudinally and at various degrees of obliquity, and envelop the hard parts according to their direction. The bones are twisted upon themselves and are furnished with articular surfaces which reflect the movements of the muscular cycles, whether these occur in straight lines anteriorly, posteriorly, or laterally, or in oblique lines in intermediate situations. The straight muscles are principally brought into play in the extension and flexion of the extremities of quadrupeds in walking, and the oblique ones in the twisting of the pectoral and caudal fins of fishes, the flippers and tails of whales, and the anterior and posterior flippers of seals in balancing and swimming, and the wings of insects, bats, and birds in flying. The straight and oblique muscles are usually found in combination, and co-operate in producing the movements in question; the amount of rotation in a part always increases as the oblique muscles preponderate. The combination of ball-and-socket and hinge-joints, with their concomitant oblique and non-oblique muscular cycles (the former occurring in their most perfect forms where the extremities are united to the trunk, the latter in the extremities themselves), enables the animal to present, when necessary, an extensive resisting surface and a greatly diminished and comparatively non-resisting one, and secures that subtlety and nicety of motion demanded by the several media at different stages of progression.

In those land-animals which take to the water occasionally, the feet, as a rule, are furnished with membranous expansions extending between the toes. Of such the otter, ornithorhynchus, seal, crocodile, sea-lion, walrus, frog, and triton, may be cited. The crocodile and triton, in addition to the membranous expansion occurring between the toes, are supplied with a powerful swimming tail, which adds very materially to the extent of surface engaged in natation. Those animals, one and all, walk awkwardly, it always happening that when the extremities are modified to operate upon two essentially different media (as, for instance, the land and the water), the maximum of speed is attained in neither. For this reason those animals which swim the best, walk, as a rule, with the greatest difficulty, and *vice versâ*, as the movements of the auk and seal in and out of the water amply testify.

The muscles in the fish, as has been explained, are for this purpose arranged along the spinal column, and constitute the bulk of the animal, it being a law that when the extremities are wanting, as in the water-snake, or rudimentary, as in the fish, lepidosiren,[1] proteus, and axolotl, the muscles of the trunk are largely developed. In such cases the onus of locomotion falls chiefly, if not entirely, upon the tail and posterior portion of the body. The operation of this law is well seen in the metamorphosis of the tadpole, the muscles of the trunk and tail becoming modified, and the tail itself disappearing as the limbs of the perfect frog are developed. The same law prevails in certain instances where the anterior extremities are comparatively perfect, but too small for swimming purposes, as in the whale, porpoise, dugong, and manatee, and where both anterior and posterior extremities are present but

[1] The *Lepidosiren* is furnished with two tapering flexible stem-like bodies, which depend from the anterior ventral aspect of the animal, the *siren* having in the same region two pairs of rudimentary limbs furnished with four imperfect toes, while the *Proteus* has anterior extremities armed with three toes each, and a very feeble posterior extremity terminating in two toes.

dwarfed, as in the crocodile, triton, and salamander. The whale, porpoise, dugong, and manatee employ their anterior extremities in balancing and turning, the great organ of locomotion being the tail. The same may be said of the crocodile, triton, and salamander, all of which use their extremities in quite a subordinate capacity as compared with the tail. The peculiar movements of the trunk and tail evoked in swimming are seen to most advantage in the fish.

§ 369. Analysis of the Movements in the Swimming of the Whale, Porpoise, Halitherium, Rhytina, Dugong, Manatee, &c.

The swimming movements of the remarkable sea-mammals are strictly analogous to those of the fish, the only difference being that the tail acts from above downwards or vertically, instead of from side to side or laterally. The anterior extremities, which in those animals are comparatively perfect, are rotated on their long axes, and applied obliquely and non-obliquely to the water, to assist in balancing and turning. Natation is performed almost exclusively by the tail and posterior half of the trunk, the tail of the whale exerting prodigious power. It is otherwise with the rays, where the pectoral fins are principally concerned in progression, these flapping about in the water very much as the wings of a bird flap in the air.

In order fully to realise the nature and extent of the swimming organs and surfaces in different kinds of animals it is necessary to study the subject from the comparative anatomy point of view. This can readily be done by a reference to Plates cliii. to clxiv. inclusive. In these Plates striking contrasts are obtained by placing certain figures, and parts of figures, in juxtaposition.

In Plate cliii. the swimming organs of the beaver, walrus, seal, sea-lion, penguin, triton, manatee, porpoise, and fish are contrasted.

In Plate cliv. the swimming arrangements of the lobster, fresh-water tortoise, fish, and bird are shown.

In Plate clv. various modern and ancient fishes are represented, and the shapes and sizes of their bodies and fins compared. They embrace the shark, swimming horse, saw-fish, goby or walking-fish, the flying-fish, sea-trout, and three ganoid old world fossil fishes.

In Plate clvi. the osseous and muscular systems and the caudal and other fins of the perch are shown.

In Plate clvii. the swimming tails of the herring, mackerel, and shark, and the swimming appliances of the skate, shark, and elephant seal are carefully drawn from nature.

In Plate clviii. the swimming arrangements of the caaing whale and bottle-nose whale are delineated.

In Plate clix. the swimming apparatus of the halitherium, rhytina, dugong, and manatee are given.

In Plates clx. and clxi. the swimming organs of the walrus, seal, and sea-lion are carefully portrayed.

In Plate clxii., original studies from the life are given of the swimming of the seal and sea-lion.

In Plates clxiii. and clxiv. the swimming and diving of the penguin, also from original studies, and the swimming of the plesiosaurus (an extinct bird-like reptile), and ichthyosaurus (an extinct fish-like reptile) are rendered with great spirit by Mr. C. Berjeau from restorations by the Author.

As the figures in the several plates referred to are carefully and fully described, and all the peculiarities of the parts engaged in natation duly noted, it only remains for me to add that I am indebted for Plates clviii., clix., and clx. to the splendid memoirs of my old friend and former colleague, Dr. James Murie, LL.D., F.Z.S. That gentleman has, with rare generosity, permitted me to publish, for the first time, his original figures and restorations of the extinct members of a fast disappearing family, namely, that of the Sirenidæ. These figures form Plate clix.

PLATE CLVIII

Plate clviii. Illustrates more especially the anatomy of the swimming organs of the caaing and bottle-nose whales and the porpoise. It brings out in strong relief the important fact, that mammals living habitually in the sea, assume the external configuration of the fish, both as regards the anterior flippers and the caudal or tail fin. So close indeed is the general resemblance that to the uninitiated the whale, which is a warm-blooded animal, is in common parlance, a fish. No finer example of a rapid vigorous swimmer can be adduced than that furnished by the caaing whale. The tail, the chief organ of propulsion, is very small considering the size of the body, but it is strongly and delicately modelled, and as it is wielded by the posterior half of the body as a long lever, and has a wide vertical sweep, it possesses prodigious propelling power. The rounded contour of the body and a profusion of oblique tendons geared to oblique muscles account for the semi-rotatory twisting movements which occur in the tail and posterior half of the body; and the great longitudinal masses of strong red muscles resembling the grand lateral muscles (myocommas) of fishes arranged above and below the spinal column with their powerful complex

PLATE CLVIII

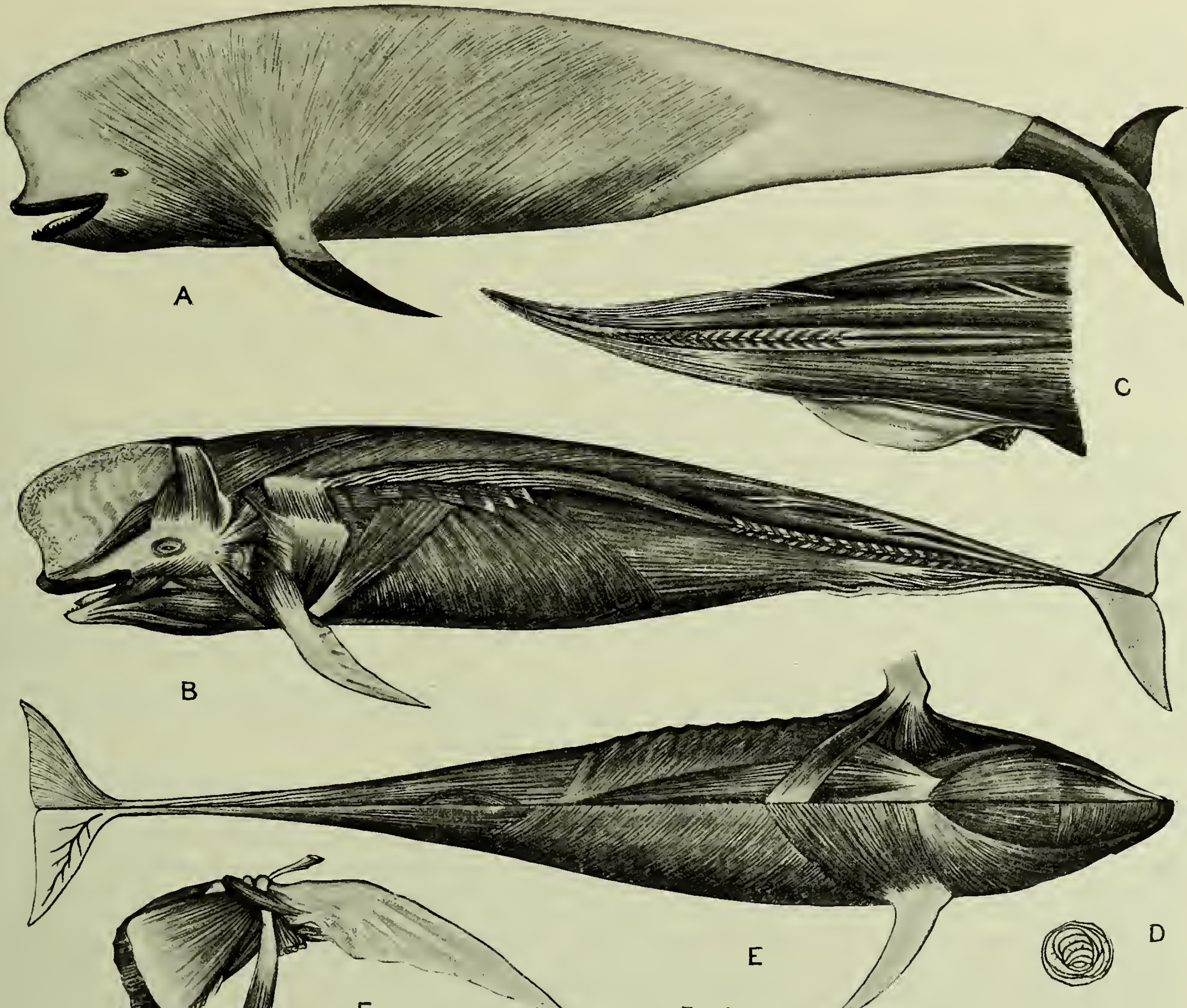


Fig. 1.

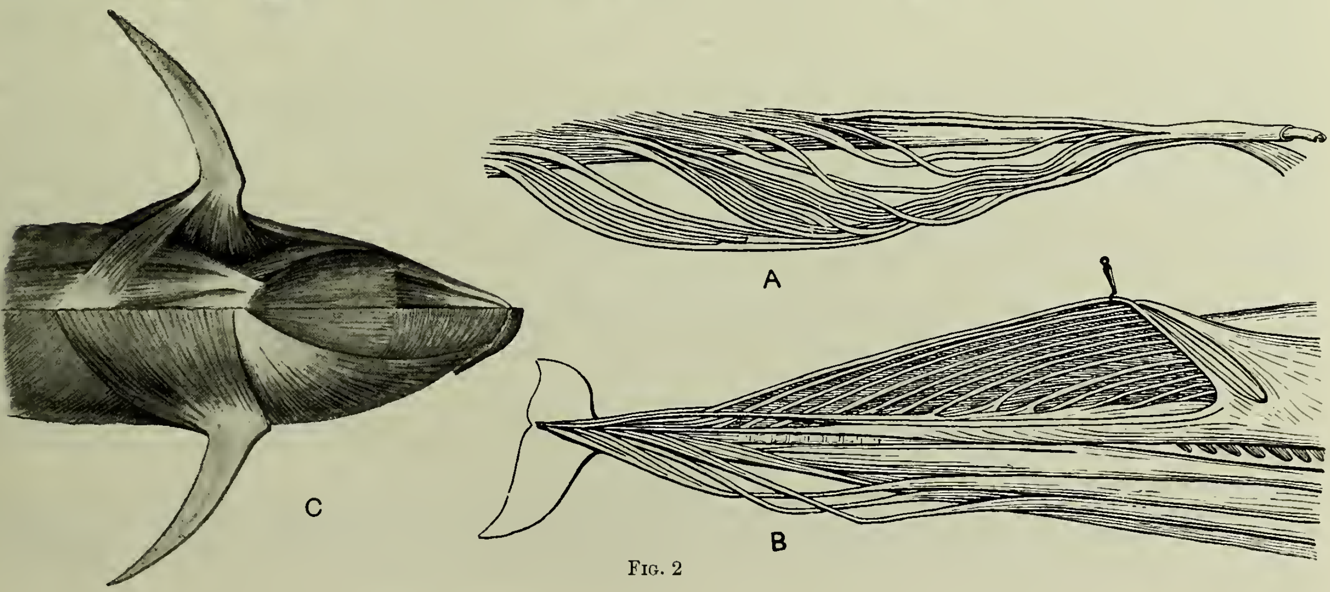


Fig. 2

PLATE CLVIII (*continued*)

tendons account for the vertical, double curve, sinuous figure-of-8 movements made by the tail during its vigorous oscillations.

The anterior flippers in the caaing whale having become greatly dwarfed may not inaptly be regarded as pectoral fins, of which they are the homologues. They are scarcely employed at all in swimming, but are very useful in balancing and turning. They have the true wing structure, being triangular in shape, elastic, thick at the roots and along the anterior margins, and thin at the tips and along the posterior margins. They have the same structure as one half of the tail, and are true propellers as the tail itself is. They are moved vertically, obliquely, and spirally by special muscles, and develop, when moving, double curve, spiral, figure-of-8 trajectories. The great range of movement possessed by the anterior flippers of whales and the pectoral fins of fishes is readily illustrated by the movements of our own arms and hands. They can be made to move forwards, backwards, laterally, and at any degree of obliquity with the greatest facility. They can also be made to circumduct and to rotate by spiral movements as in the pronation and supination of the hands, &c. (*vide* the muscular arrangements of the superior extremities in man in another part of the work).

It should be stated in connection with the great reduction in the size of the flippers in the caaing and bottle-nose whales that the posterior flippers have entirely disappeared ; their place being taken by what is, virtually, a powerful fish tail. This fact corroborates in a striking manner the absolute necessity for sea mammals, which spend their lives in the water, conforming to a general plan or type as regards their form, and the size and shape of their swimming organs.

The type, it need scarcely be stated, is that of the fish, which combines in itself all the mechanical advantages referred to. The movements peculiar to locomotion on the land, and in the water and the air, have many points in common, and there is a striking analogy between the movements of swimming and flying animals ; this analogy extending to the travelling organs themselves. It has only to be added that animals move along the three great highways of nature (the land, the water, and the air) not in an accidental haphazard way, but according to law and order ; their travelling organs being specially modified so as to secure all the mechanical advantages which the most advanced physics and the highest applied mathematics can secure.

Fig. 1.—Shows the superficial and deep anatomy of the caaing whale (*Globiocephalus melas*), and the posterior portion of the white-beaked bottle-nose whale (*Lagenorhynchus albirostris*), and porpoise (*Phocœna communis*).

A. Body of the female caaing whale, from which the skin and the layer of fat beneath it have been removed, a portion of the pectoral fin and tail excepted. Shows a great triangular superficial layer of muscle (panniculus carnosus) converging on the root of the left anterior flipper or pectoral fin. The lighter portions of the figure are covered with strong fasciæ. The general fish-like shape, and the beautifully modelled pectoral and caudal fins, are delineated with great fidelity.

B. A deeper dissection of the same whale seen from the left side. Shows the intrinsic or special muscles of the left anterior flipper or pectoral fin, the costal muscles, and the great longitudinal muscles placed above and below the spinal column, which, by the aid of their numerous tendons, confer a vertical, double curve, sinuous movement on the tail. Between the great longitudinal muscles referred to, and nearer the spine, oblique muscles occur which cause the tail to twist and partially rotate during its vertical oscillations and so add to and complete the figure-of-8 sculling movements made by it.

C. The same arrangements in the posterior half or tail portion of the white-beaked bottle-nose whale.

D. Semi-diagrammatic view of a transverse vertical section of part of the caudal keel of the caaing whale. Shows the lateral, compressed, or vaginate tendons of the sacro-coccygeus muscles (see A and B of Fig. 2).

E. Abdominal view of the female caaing whale ; the lower (left) half of the figure displaying a superficial dissection—the upper (right) half, a deeper dissection. The course of the muscular fibres of the several muscles indicates the direction in which the muscles act.

F. Inner aspect of the left pectoral limb and of fin showing the left anterior flipper and the intrinsic muscles and tendons connected therewith (compare with similar parts of Fig. 1, E ; and of Fig. 2, C). It will be seen, and this is important, that the fin is elastic, triangular in shape, thick at the root and along the anterior margin, and thin at the tip and along the posterior margin. In this respect it represents the highest form of pectoral fin in fishes ; and very closely resembles structurally (and, it may be added, functionally) the wing of the insect, bird, and bat. *Vide* the wings of insects, birds, and bats further on.

Fig. 2.—Shows the complex arrangement of the caudal or tail tendons in the caaing whale and porpoise ; also the wing-like pectoral fins of the former as seen from beneath exposed by superficial and deep dissections.

A. Diagram showing the manner in which the tendons of the great inferior loin muscle terminate in the caaing whale. The sacro-coccygeal, secondary tendons are dragged out, but unite to form a circular sheath through which the thick compressed terminal tendon of the tail passes.

B. Dissection of the posterior portion of the body of the porpoise showing the elaborate arrangement of the straight and oblique tendons connected with the caudal fin and tail, on which the peculiar double curve sinuous twisting spiral movements of that organ mainly depend.

C. Superficial and deep dissection of the ventral or under surface of the anterior third of the body of the caaing whale. Shows the exquisitely modelled anterior flippers or pectoral fins, which structurally greatly resemble true wings, in that they are triangular in shape, elastic, thick at the roots and along the anterior margins, and thin at the tips and along the posterior margins. The superficial and deep muscles which move or actuate the fins are carefully and accurately drawn.

PLATE CLIX

Plate clix. Illustrates the anatomy and swimming arrangements of that most interesting but rapidly disappearing family, the Sirenia, composed of the halitherium, rhytina, dugong, and manatee. The halitherium and rhytina are extinct, and the dugong is nearly so. The manatee still lingers in South America, but in no great numbers.

The finest example of the family, as far as size and swimming power are concerned, was the rhytina, which measured from twenty to twenty-five feet long. It possessed a small head, a large, rounded, fish-shaped body, fairly well developed anterior flippers, and a small but splendidly modelled swimming tail, resembling the tails of the Cetacea. It was doubtless a powerful and rapid swimmer. A restoration of this most interesting form is shown floating on a sheet of ice, the lowest figure of Fig. 1 of the Plate. Above it, and to the right of the Plate, is seen the dugong; while above the rhytina, in the centre of the Plate, is a restoration of the halitherium. To the left of the Plate, above the rhytina, is the manatee. In the rhytina, dugong, and manatee the posterior extremities or flippers have wholly disappeared (as in the Cetacea), and a swimming tail has taken their place. The general appearance of these animals is fish-like, and their mode of swimming is the same as in the fish, with the difference, that the tail is made to oscillate *vertically* instead of laterally or from side to side.

In the restoration of the halitherium the head and anterior extremities or flippers are represented as larger than in the rhytina, dugong, and manatee; and small posterior extremities or flippers which, as stated, are wanting in the rhytina, dugong, and manatee, are added. The tail, moreover, is made to differ from the others in that it is of an oval pointed form. The idea is to make it a transition or connecting link as between ordinary quadrupeds on the one hand, and sea mammals on the other. The suggestion is ingenious, but must be received with caution, as we have no proof that the land quadrupeds were the parents and precursors of the sea mammals. The evidence, so far as it goes, inclines to the belief that separate creations were required for the production of land and water animals respectively.

Fig. 1.—Shows original drawings and restorations (taking the upper three figures from left to right) of the manatee (*Manatus americanus*), halitherium (after Murie), dugong (*Halicore dugong*), and (lower figure) rhytina (*Rhytina stelleri*).

Fig. 2.—Dissections of a young manatee, showing the osseous and muscular systems, and the construction of the anterior flippers and caudal fin or tail.

A. The osseous system of the manatee, as seen from the left side. The skeleton of the manatee is remarkable for its great elegance, strength, and weight. The vertebral column, which extends from the head to the posterior or free extremity of the tail, is strongly and beautifully built, and displays three curves—a cervical, a dorsal, and a caudal. The ribs are strongly arched, and the vertebral column and ribs, taken together, convey the idea of great strength and power—an idea fully borne out by the greatly developed muscular system, and the large, well-formed, triangular rounded tail, which is elastic, and graduated from its root, where it is thickest, to its free margins, where it is thinnest. The posterior half of the vertebral column and the tail are expressly constructed to admit of vertical oscillations when the animal is swimming. The manatee, like other sea mammals, lashes its tail alternately from above downwards and from below upwards. It also confers a certain amount of rotatory twisting movements on its tail, which is the chief organ of propulsion. The tail acts after the manner of a scull, and produces double curve figure-of-8 movements.

B. Transverse section of the posterior portion of the body. Shows the great muscular masses placed symmetrically on either aspect of the vertebral column, which confer on the tail its great power and swimming capacity. The muscular masses resemble similar masses in the fish, with this difference, that the principal masses are placed above and below the spinal column instead of laterally as in the fish; a modification necessitated by the tail being made to oscillate vertically instead of laterally in swimming.

C. Transverse section of the tail showing that it is graduated from the spinal column or central point where it is thickest towards its free margins where it is thinnest.

D. Superficial dissection of the muscular system of the manatee, as seen from the left side. Shows the great longitudinal and oblique muscular masses—the former predominating on the trunk, the latter on the tail portion of the trunk. The arrangement of the oblique muscles on the tail portion of the trunk confers on the tail the vertical double curve and twisting sculling movements which characterise it. In this figure the tail is not shown. The left flipper, however, is represented in its natural position; its dorsal surface being presented to the spectator. The palmar surface of the flipper is seen at G. The flipper is webbed and its five digits may be separated and approximated at pleasure. It has a full complement of straight and oblique muscles, and can be made to perform, more or less perfectly, the several movements witnessed in the human arm and hand; that is, it can be moved backwards, forwards, outwards, and inwards. It can also be flexed and extended and made to circumduct, to rotate up to a point, and to pronate and supinate within limits. Its movements are, in a sense, universal; a fact which enables the animal to apply it to the water in a flexed or extended condition, with the digits approximated or spread out, and with its slightly concave flattened surfaces inclined at any desired angle. As a balancing and turning organ it is most useful to its possessor. It, however, takes little part in swimming; the real propulsive organ being the tail. The manatee is, on the whole, a sluggish animal, but it has the appliances for occasional rapid swimming.

I had an opportunity of studying a living adult specimen in the Westminster Aquarium, London, in July 1878, and made out the following points regarding its flippers:—

1. The flippers when in action make figure-of-8 movements.
2. The up strokes are made upwards and forwards, and the down strokes downwards and backwards.
3. During the up strokes the flippers are partly flexed and drawn towards the body; the flippers presenting rounded narrow oblique cutting edges; the slightly concave, flattened surfaces being more or less parallel with the body.
4. During the down strokes, the flippers are partly extended and made to rotate, so that their under, slightly concave flattened surfaces are more advantageously applied to the water.

PLATE CLIX

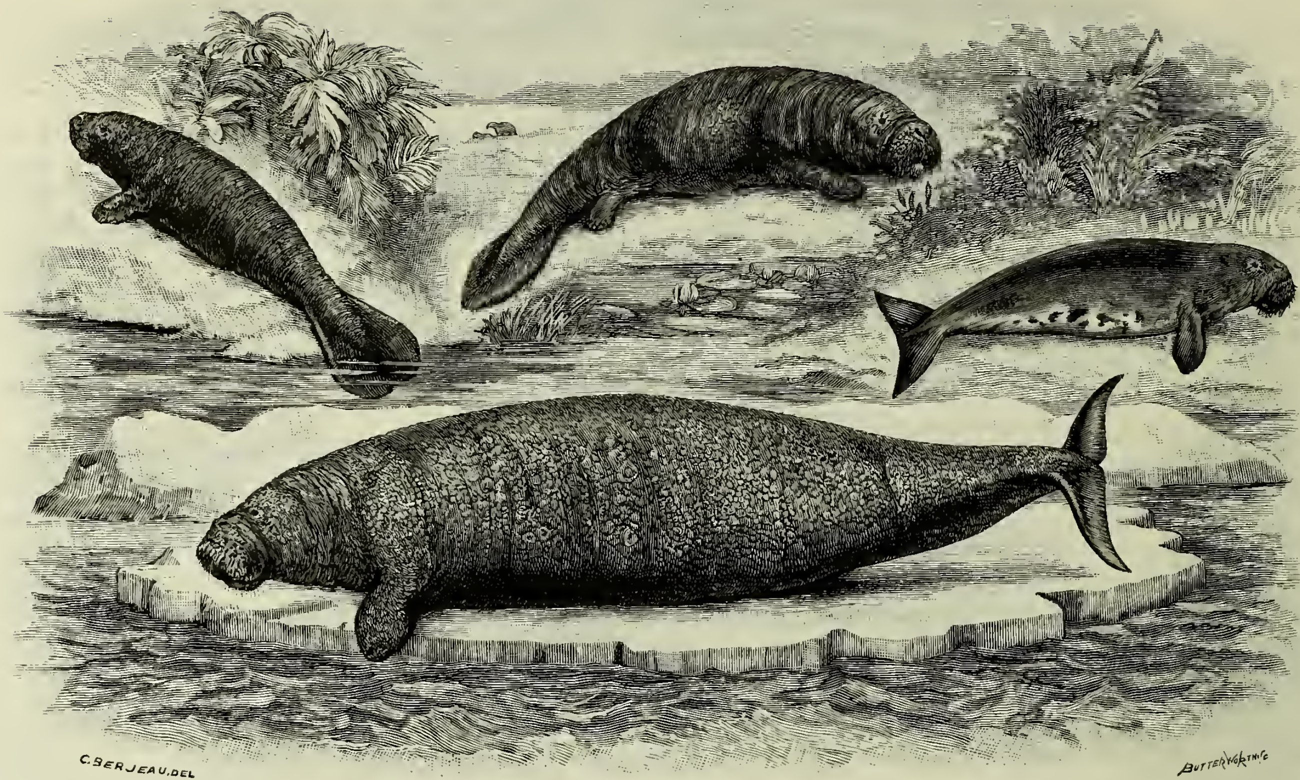


Fig. 1

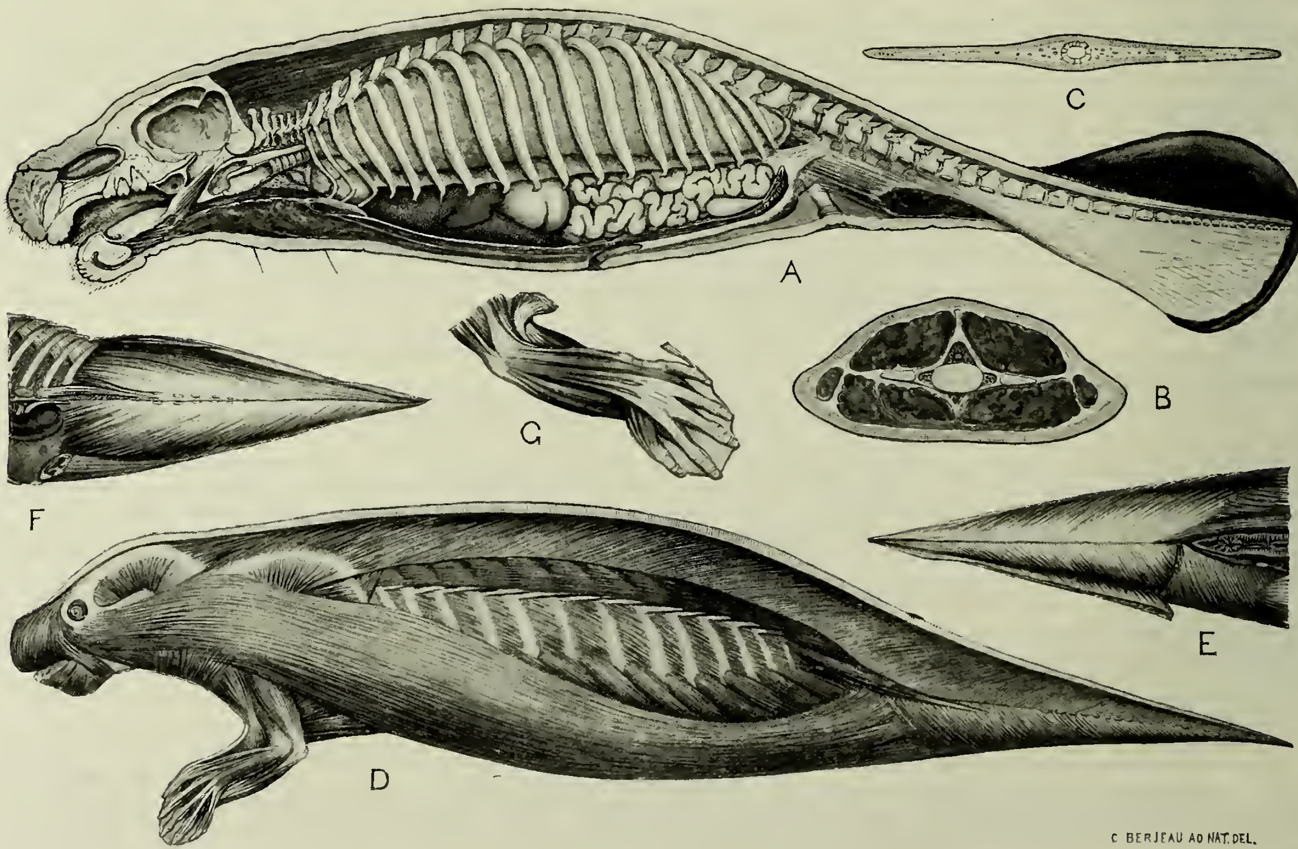


Fig. 2.

PLATE CLIX (*continued*)

5. The angles made by the flippers during the downwards and backwards stroke are, when greatest, something like 45°. The angles, however, vary at successive stages of these strokes.

E. Superior and deep oblique muscles occurring on the ventral or under surface of the posterior third of the body of the manatee, which are largely instrumental in conferring twisting, semi-rotatory movements on the tail in swimming.

F. Ventral view of the oblique lumbo-caudal muscles found on the posterior portion of the body. These muscles, as their direction indicates, confer spiral twisting, semi-rotatory movements on the tail when it is made to oscillate vertically in swimming.

G. Palmar surface of the left flipper or fin. Shows the five digits of the flippers with the membrane or web extending between them; also the muscles of the forearm. Compare with the muscles of the left superior human limb in another portion of the work. (The figures and dissections in this Plate (clix.) are by Dr. James Murie: the descriptions by the Author.)

PLATE CLX

§ 370. Analysis of the Swimming Movements of the Walrus, Seal, and Sea-Lion.

Plate clx. Shows the swimming appliances of the walrus (*Trichechus rosmarus*), seal (*Phoca vitulina*), and sea-lion (*Otaria*). The flippers of the walrus, seal, and sea-lion each display five digits which can be separated and brought together at pleasure. A swimming membrane or web extends between the digits, and this membrane is alternately put upon the stretch and relaxed during the oscillations of the limbs in swimming. This Plate also furnishes admirable dissections of the anterior flippers of the walrus and sea-lion (Figs. 4 and 5). Dissections of the posterior flippers of the sea-lion and seal are given at Plate clxi., Figs. 1 and 3. Especial attention is directed to the straight and oblique muscles and tendons of the flippers, whereby the flippers are flexed and extended and partially rotated; the flippers being tilted at discretion, and presenting oblique and non-oblique surfaces to the water.

Fig. 1.—Drawing made of a young male walrus, by Mr. Wood from the life. Shows the anterior and posterior flippers in the semi-flexed condition when the animal is in a resting attitude.

Fig. 2.—Dorsal view of the left anterior flipper of the walrus partially flexed, with its five digits very slightly separated, and showing the swimming membrane or web between. The numerals indicate the digits (after Murie).

Fig. 3.—Dorsal view of the right posterior flipper of the walrus with the sole twisted backward as in the act of swimming. The flipper from the heel alone appears free. The five digits are spread out, and the membrane or web between them put upon the stretch, though not to the full extent. The numerals indicate the digits (after Murie).

Fig. 4.—Left anterior limb and flipper (dorsal surface) of the walrus dissected to show the muscles of the left shoulder, arm, forearm, and hand; also the tendons of the muscles, and the membrane or web extending between the five digits. The general arrangement is virtually that found in the left superior extremity of man. A study of the straight and oblique muscles and their tendons shows how the limb and flipper are flexed and extended, how rotated, tilted, and twisted, and how the digits are separated and brought together at pleasure. The limb and flipper are entirely under the control of the animal, and can practically be moved in every direction. The same is true of the posterior flippers, which, in swimming, are made to oscillate laterally or from side to side as in the sea-lion, seal, and fish, and to produce a double curve figure-of-8 trajectory. The posterior flippers, while executing what is virtually a reciprocating sculling motion, rotate slightly in the direction of their length and so add the element of spirality to the sculling movements (after Murie: the movements analysed and described by the Author).

Fig. 5.—Dissection of the left anterior limb and flipper (dorsal surface) of the sea-lion. Shows the same parts as in Fig. 4, so that the description of that figure need not be repeated. The straight and oblique muscles and their tendons indicate their function and tell their own tale, and no finer example of a swimming membrane than that seen in the flipper under observation can anywhere be found. The peculiarity in the swimming of the sea-lion, and it is a remarkable one, is that it employs its anterior flippers as wings, and literally flies through the water after the manner of the auks and penguins; its posterior flippers taking very little part in the forward movements, and, in many cases, being spread out at right angles to the body and acting as a drag for regulating the degree of speed. The anterior flippers of the sea-lion are graduated and taper in every direction, after the manner of true wings; being thickest at the roots and along the anterior margins, and thinnest at the tips and along the posterior margins. They are endowed with, practically, universality of movement—flexion, extension, abduction, adduction, circumduction, semi-rotation, tilting, twisting, &c. To the other movements are to be added the power of divaricating and approximating the digits which alternately increases and diminishes the area of the flippers. As the flippers are exceedingly mobile, flexible structures, and can be moved at will in every direction, they give to the sea-lion complete control of the element in which it is immersed. The sea-lion flies through the liquid medium with incredible speed; its movements in the water being as graceful as they are laboured and awkward out of it (after Murie).

Fig. 6.—Hind flippers of the elephant seal, in the unexpanded and expanded conditions. Each flipper displays five digits and a swimming membrane or web between them. The difference in the area of the flippers in the unexpanded and expanded condition is very considerable, and indicates the difference in the amount of bite secured in the effective and non-effective portions of the strokes when the seal is swimming. (Drawn for the present work by C. Berjeau.)

PLATE CLXI

Plate clxi. Shows one of the posterior flippers of the sea-lion, and the osseous and muscular arrangements of the seal.

Fig. 1.—Left posterior flipper of the sea-lion—dorsal aspect. Shows the osseous, muscular, tendinous, and webbed arrangements of the flipper, and its connection with the pelvis. The action of the muscles is indicated by the direction of their muscular fibres, and the distribution of their tendons. Due provision is made for the lateral oscillation, flexion, extension, abduction,

PLATE CLX

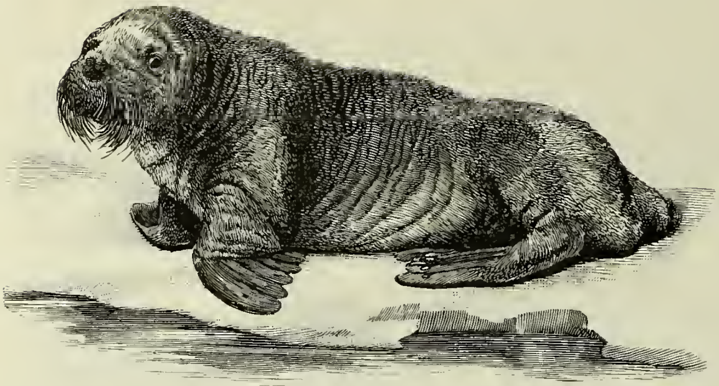


Fig. 1.

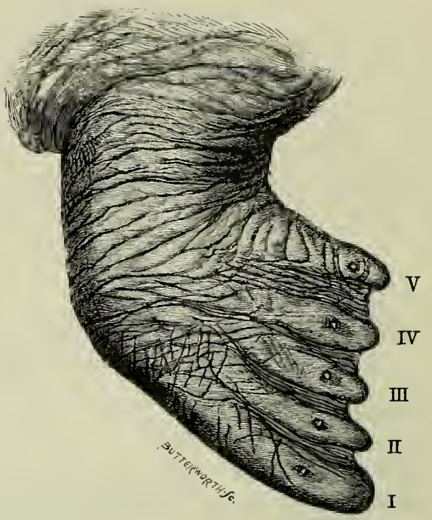


Fig. 2.

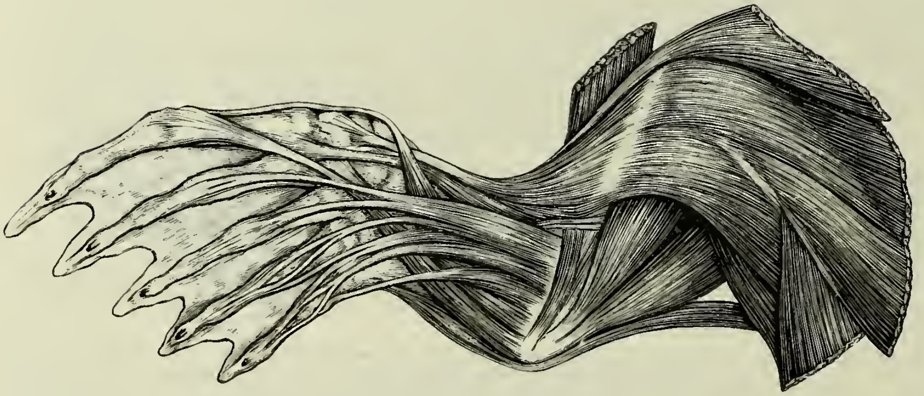


Fig. 4.

Fig. 3.

Fig. 6.

Fig. 5.

PLATE CLXI

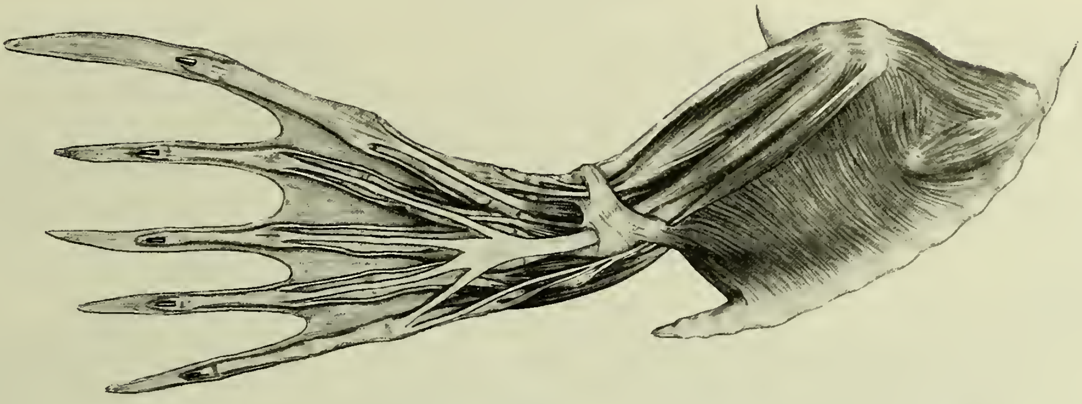


FIG. 1.

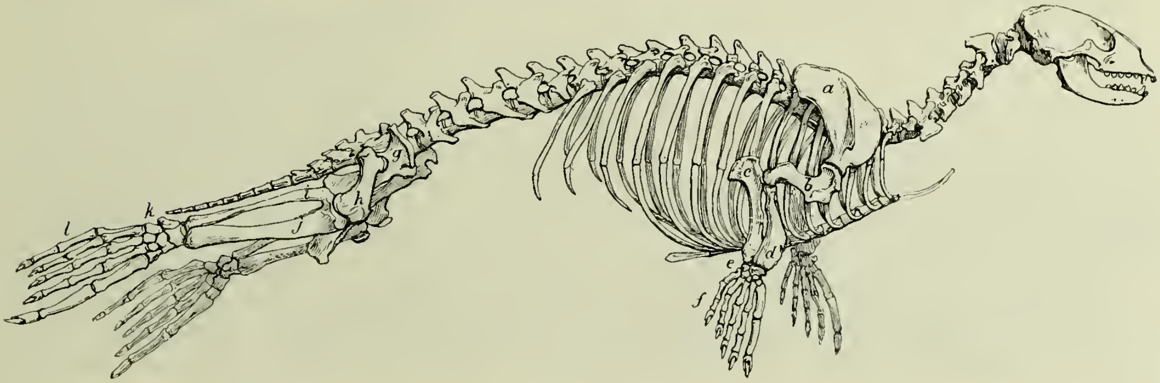


FIG. 2.

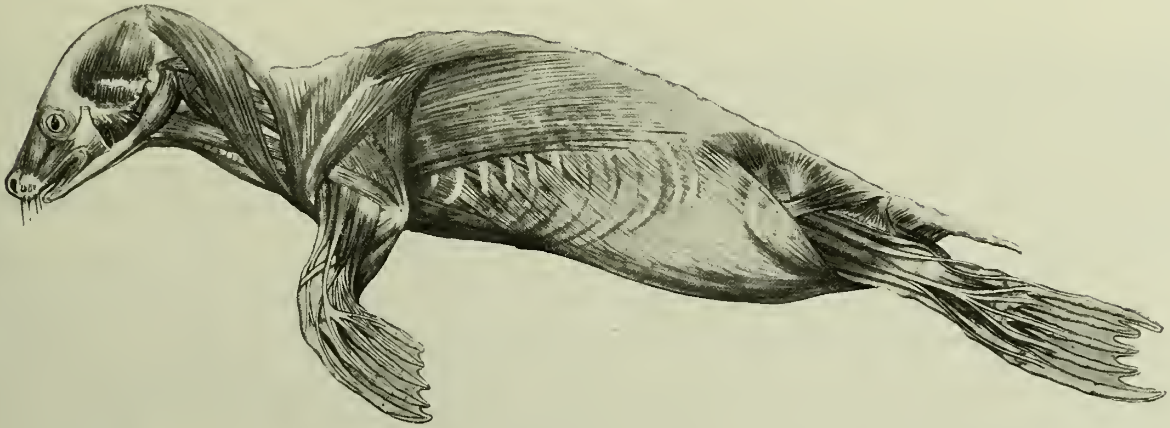


FIG. 3.

PLATE CLXI (*continued*)

adduction, circumduction, semi-rotation, and increase and decrease of the web of the flipper. The posterior flippers of the sea-lion form effective swimming organs, but they are chiefly employed as balancers and drags for steadying, regulating, and slowing the forward movement acquired by the vigorous flying movements of the anterior flippers. When used as drags they are placed at right angles to the body, and encounter quite an extraordinary degree of resistance from the water. The swimming movements of the sea-lion and seal are fully illustrated in Plate clxii., which see (after Murie : movements described by the Author).

FIG. 2.—Skeleton of the seal. Shows the strong, beautifully curved vertebral column tapering backward ; the slender ribs ; the large scapula and greatly modified anterior limbs and flippers; also the curiously shaped pelvis; and the powerful, greatly modified, posterior limbs and flippers which are the chief swimming organs. The vertebral column and the posterior extremities and flippers of the seal are specially constructed to admit of the posterior limbs and flippers being lashed from side to side in swimming, after the manner of the fish. The modifications in the anterior and posterior extremities of the seal are very remarkable and deserve very special consideration and study in their relation to homology and teleology. *a*, Right scapula ; *b*, humerus or arm bone ; *c*, *d*, radius and ulna (bones of forearm) ; *e*, wrist bones ; *f*, metacarpal bones and digits (hand bones) each five in number ; *g*, pelvis or hip bone ; *h*, femur or thigh bone ; *i*, *j*, tibia and fibula (leg bones) ; *k*, ankle bones ; *l*, metatarsal bones and digits (foot bones) each five in number. (Drawn from a carefully articulated skeleton by C. Berjeau for the present work.)

PLATE CLXI (*continued*)

FIG. 3.—The muscular system of the seal. Shows a really admirable dissection of the muscles of the head, neck, and trunk, and of the anterior and posterior extremities and flippers.

The distribution of the muscles in the limbs and flippers deserves careful study, as it throws a flood of light on the swimming movements of the seal. The muscles of the neck and trunk, as will be seen, converge towards the anterior limb and flipper, and the muscles of the shoulder are folded round the scapula (shoulder blade) and root of the limb so as to secure a certain amount of circumduction and rotation for it. The elbow, wrist, and finger joints, because of the attachments and direction of the contiguous muscles, can be readily flexed and extended, and the digits separated and brought together as required. The limb can also be made to move in an upward, downward, forward, and backward direction. It can likewise be more or less completely pronated and supinated. The limb is practically endowed with universality of motion ; a state of matters which enables the seal to seize and let go the water, when balancing and turning, with celerity and certainty, whether the water be in a calm or disturbed condition. The ease and grace with which the seal balances. turns, and swims are proverbial.

What is said of the anterior extremities and flippers is equally true of the posterior extremities and flippers. They are endowed with similar muscles and movements. The posterior extremities are thrust out of the plicated muscular folds of the posterior portion of the body like a straight, amply-bladed oar from the stern of a boat, and, curiously enough, the movements of the oar in sculling are identical with the movements of the posterior extremities and flippers of the seal in swimming. An examination of the muscles and tendons of the posterior extremities and flippers shows that they are distributed in straight lines and obliquely; an arrangement which in swimming produces not only the lateral double curve sinuous figure-of-8 movements, but also the rotatory and tilting movements which constitute the sculling motion proper. (Drawn from a carefully dissected specimen for the present work by C. Berjeau.)

PLATE CLXII

Plate clxii. Life studies of the swimming of the sea-lion and seal by the Author, specially drawn for the present work by C. Berjeau.

Nothing can exceed the extraordinary variety, vigour, celerity, and elegance of movements displayed by the sea-lion in swimming and diving. It develops with amazing rapidity the most beautiful double curves in its body and flippers, and these curves it is incessantly changing. All its movements are sinuous, reciprocating, wave movements. It is a perfect master of every conceivable kind of aquatic movement. Its anterior extremities and flippers are its chief organs of propulsion. These structurally resemble aerial wings, being triangular in shape, elastic, and carefully graduated ; that is, they are thickest at the root and along the anterior margin, and thinnest at the tips and along the posterior margin. The anterior flippers are bent slightly backwards towards their tips or free extremities, in which respect they also resemble aerial wings. Similar wing-like structures are seen in the turtle (Fig. 499, p. 1159) and also in the penguin (a bird which does not fly in the air but only swims and dives in the water (Fig. 1, Plate clxiii.), and in the extinct bird-reptile (*Plesiosaurus*) and the extinct fish-reptile (*Ichthyosaurus*). These anomalous forms are illustrated in Plate clxiii., and have much significance as bearing on the locomotion of the sea-lion. The swimming of the seal is quite as graceful and vigorous in its way as that of the sea-lion. It is accomplished by the lateral lashing of the posterior extremities and flippers after the manner of the fish—the anterior extremities and flippers acting in a subordinate capacity, chiefly in balancing and turning movements. The reciprocating wave movements and double curves developed in the swimming of the sea-lion are reproduced in the swimming of the seal.

The characteristic difference between the two consists in this—the sea-lion in swimming mainly employs its anterior extremities and flippers as wings, after the manner of flying birds ; the seal, on the other hand, mainly employs its posterior extremities and flippers as caudal fins or tails, after the manner of fishes.

The muscular power exercised by the fishes, the cetaceans, and the seals in swimming, is conserved to a remarkable extent by the momentum which the body rapidly acquires—the velocity attained by the mass diminishing the degree of exertion required in the individual or integral parts. This holds true of all animals, whether they move on the land or on or in the water or air.

In order to grasp the central idea in the swimming and diving of the sea-lion and of the other animals referred to, it is necessary to say a few words regarding the structure and movements of wings proper. All wings are similarly formed and similarly applied to the air. They are all triangular in shape, slightly concavo-convex, elastic, and taper from the root towards the tip, and from the anterior towards the posterior margin. They are thickest at the root and along the anterior margin and thinnest at the tip and along the posterior margin. Artificial wings on the above pattern can readily be constructed by the aid of tapering bamboo canes, ribbon-steel, and silk, cambric, buckram, or other light covering material. The tapering bamboos and ribbon-steel are made to radiate from the root outwards and backwards—the backwards radiation being least at the tip and greatest towards the root. A wing so constructed, as I showed in 1867, 1870, and subsequently, if held in the right hand with its anterior thick margin directed to the left and its flat surface towards the earth and made to vibrate in a vertical direction, immediately darts forward to the left in a series of horizontal undulations or curves ; it describes a horizontal waved trajectory in the air. If the wing has its anterior thick margin elevated, so that its under surface makes an

PLATE CLXII

Fig. 1.

Fig. 2.

angle of 45° with the horizon and the wing be made to vibrate in a vertical direction, it immediately darts upwards and forwards (to the left) in a series of oblique upward undulations or curves. Finally, if the wing have its anterior thick margin directed vertically upwards, and be made to vibrate in a horizontal direction, it immediately darts upwards in a series of vertical undulations or curves. If, on the contrary, the anterior thick margin of the wing be depressed instead of elevated, all the movements in question are reversed.

The forward movement of the wing in a horizontal, oblique, and vertical direction is due to the fact that it is elastic in all its parts and yields readily to atmospheric resistance (especially at its tip and along its posterior margin) when the wing is made to oscillate vertically, and it is brought violently in contact with the air.

Thus, when the anterior thick margin of the wing is slightly raised and the wing is suddenly elevated in a vertical direction, the posterior thin margin yields in a downward direction in virtue of the resistance experienced by its upper surface from the superimposed air. The wing, under these circumstances, darts upwards and forwards in a curve. When the wing held in the same position is suddenly depressed in a vertical direction, its posterior thin margin yields in an upward direction because of the resistance experienced by its under surface from the nether air. In this case, the wing darts downwards and forwards in a curve. When the upward and downward curves made by the wing during the up and down strokes are united, as they always are, by the running or gliding of the up and down strokes into each other, a waved-trajectory is the result; this trajectory representing continuous flight. What is here stated of the wing with its anterior thick margin slightly raised and the upward and downward vertical strokes is true of it in all its other positions, that is, when the angle made by the wing with the horizon is increased and the strokes are delivered more and more obliquely until the thick margin of the wing is directed vertically upwards and the strokes are horizontal. These experiments, fully described and figured by me in 1867 and 1870, conclusively prove that the wing is essentially a propeller, but that it propels and also elevates and sustains when the axis of the body of the insect, bird, and bat, and the axis of the under surface of their wings, are inclined at various upward angles, kite-fashion, to meet new and ever changing conditions. I further explained, at the dates referred to, that the caudal or tail fin of the fish has a common structure with the wing, and is likewise a propeller, and that it can propel the fish in a series of undulations or curves in a horizontal direction, or in an oblique upward, downward, or lateral direction; the course being determined by the direction assumed by the root, or thick and more unyielding portion, of the tail for the time being. The wing and the fish tail obviously act on a common principle.

A factor of great importance in the experiments and observations just alluded to is the relative weight of the swimming and flying animals to the water and air respectively. In the case of the fish and sea mammals, which navigate the water, their bodies are very nearly of the same specific gravity as that medium. In the case of insects, birds, and bats, which navigate the air, their bodies are immensely heavier than the medium which floats them and affords them support. As a consequence, the fish and the sea mammals, such as the porpoise, whale, walrus, seal, and sea-lion, have only to change the long axis of their bodies and the inclination of their swimming organs in order to swim in a horizontal, upward, downward, or lateral direction. The mere change of the axis of the body and of the angle of inclination of the swimming organs suffices to ensure swimming, diving, and flying in the water in any of the directions indicated. It is therefore no metaphor to say, in the case of the sea-lion, that the animal flies in the water in a horizontal, upwards, downwards, or lateral direction at pleasure. If the head, neck, trunk, and anterior and posterior extremities and flippers of the sea-lion occupy a position parallel to the surface of the water, the animal flies in a horizontal direction. If, on the other hand, the long axis of the body and the angle of inclination of the parts in question be directed upwards, the animal flies upwards. If, finally, the axis and angle of inclination be directed downwards, the animal flies downwards. To this there is no exception.

Precisely the same thing happens in the swimming and diving of the penguin figured in Plate clxiii.

In the case of insects, birds, and bats, which have constantly to contend with gravitation, which relentlessly pulls them downwards, the axis of the body and the upward angles of inclination of the under surfaces of the wings are considerably increased. As a consequence, the down strokes of the wings are not delivered vertically downwards, but downwards and *forwards*, as I showed more than thirty years ago. According to old ideas the wings struck either *vertically downwards* or *downwards* and *backwards*, and so *pushed* the body of the volant animal upwards and forwards. As a matter of fact, and, as proved again and again by instantaneous photographs of flying birds, the wings strike *downwards* and *forwards* and *pull* the body forwards. The result is the same, but the *modus operandi* is wholly different.

In a volant animal (which is a body in motion) the wings must be kept in advance of the body to afford it the necessary degree of support. A body in forward motion in the air does not tend to fall vertically downwards, and, still less, downwards and backwards. On the contrary, it falls, or tends to fall, downwards and forwards in a curve, and the wings must be placed in advance of the body with their under surfaces arranged at certain upward

angles after the manner of kites to afford the greatest possible support. Swimming, diving, and flying are largely mechanical problems, but they are not wholly so, and all living animals which resort to these forms of locomotion are constantly putting forth voluntary efforts. In other words, swimming and flying animals regulate and control all their movements whether great or small. Questions of balance, pressure, resistance, speed, direction, buoyancy, &c., are constantly cropping up and require to be instantly solved if a pending catastrophe is to be averted. As regards flying, it is commonly believed that it is a mere question of levity and power. There can be no greater mistake than this. Flight can only be achieved when all the mechanical conditions are satisfied, and when the weight and power are perfectly adjusted and the various forces at work intelligently and voluntarily controlled. Flight is no random or accidental problem. On the contrary, it forms the Gordian knot of the most advanced physics and applied mathematics. Flight can only be accomplished by availing ourselves of the law and order which everywhere prevail in the universe, inanimate and animate. It is a means to ends, and, as such, implies Design of the highest possible order.

From what has been stated it will be evident that the flying of the sea-lion figured in the present Plate (clxii.), and of the penguin and extinct animals figured in Plate clxiii., have much in common with each other. They have also much in common with the flight of insects, birds, and bats, and with the swimming of the fish, seal, walrus, &c.

In Fig. 1 of Plate clxii., the lower sea-lion to the right is flying downwards; the lower sea-lion to the left flying upwards. The upper sea-lion to the right, with its posterior extremities and flippers spread out at right angles to the body, is slowing and arresting its forward movement. The two upper sea-lions on the rocks to the left show the characteristic attitudes and movements of the animals on land.

Fig. 2 of Plate clxii. illustrates life studies of the swimming of the seal by the Author, specially drawn for the present work by C. Berjeau.

The swimming of the seal in all respects resembles that of the fish already described, that is, it is effected by the vigorous lateral lashing and twisting figure-of-8 fashion of the posterior extremities and flippers. The anatomy of the posterior extremities and flippers is given at Fig. 3 of Plate clxi. In this figure dissections are also given of the anterior extremities and flippers. The figure in question (3) and its description illustrate the more important points not only in the anatomy but also in the physiology of the swimming organs of the seal.

Fig. 2 of Plate clxii. shows the seal in several characteristic attitudes. The lower seal on the right is seen immersed and swimming fish-fashion. The lower seal to the left is scrambling up the rocks by means of its flippers and the wave-movements of its body. The seal in the middle has gained a flat shelving rock and is hobbling forward on its ventral surface by its anterior flippers and sinuous body movements; the posterior flippers being high in air. The double curve movements made by the body of the seal in swimming are indicated in the figure to the left, and are well seen in young lean seals. I witnessed them to perfection in a young underfed seal at the aquarium in Zurich several years ago, and was much impressed by the wonderful agility and grace displayed by the animal in its watery element. Every movement revealed new double-curve lines of beauty, and these followed each other so rapidly that the spectator had barely time to note and analyse them. It has only to be added that the seal swims with equal facility on its ventral and dorsal surfaces.

§ 371. The Swimming of the Penguin.

The swimming and diving of the penguin are full of interest to all students of natural history and animal locomotion (Plate clxiii.). This active bird floats deeply in the water, and, when not diving, propels itself along its surface by the aid of its powerful webbed swimming feet. It dives and flies under the water by means of its small modified wings, which are covered with very minute feathers; the latter being of no use whatever in flying in the air. While the wings of the penguin are too small to accomplish aerial flight, they are genuine wings as regards their shape and structure, that is, they are triangular, elastic, and carefully graduated organs; being thickest at the roots and along the anterior margins, and thinnest at the tips and along the posterior margins. Like aerial wings, they yield in every direction, especially along their posterior margins, under pressure. When the penguin dives preparatory to flying under the water, it makes a little upward and then a downward leap to get under the surface. When submerged its wings are moved with incredible rapidity. It flies in a downward, upward, horizontal, and lateral direction with equal precision and certainty. When the long axis of the body and the angles of inclination of the wings are directed downwards, the bird flies downwards; when these conditions are reversed it flies upwards. When the long axis of the body and angles of inclination of the wings are parallel with the surface of the water, it flies in a horizontal direction. The bird turns to right or left by tilting its body and wings laterally, or by the unequal pressure of the latter. It moves with the greatest adroitness and ease in whichever direction it pleases. It is a rare treat to watch the penguin swimming, diving, and flying in roomy tanks in large aquariums, or

what is still better, to study its tactics from a coign of vantage through a powerful field-glass in some land-locked bay.

The penguin has perfect control over its small, aborted, and yet most effective wings. At times it twists and untwists them screw fashion, and employs them as reversing, reciprocating organs as shown at Fig. 6 of Plate cliii., p. 1148.

The following is an abstract from my notes of the swimming and diving of a penguin, as witnessed by me at the Zoological Gardens, London, on the 11th of July, 1880 :—

1. The bird swims very deeply ; so much so that its aborted wings or flippers are submerged.

2. The flippers are directed backwards, and it is in this direction that the effective stroke is delivered.

3. The concave or ventral surface of the flipper is presented to the water during the effective stroke ; the flipper being slightly twisted upon itself for the purpose.

4. When the effective stroke is being made, the anterior or thick margin of the flipper is directed slightly downwards. This happens in horizontal flight.

5. When the bird flies downwards, the head and body are directed downwards and the effective stroke is delivered downwards and backwards.

6. When the bird flies upwards, the head and body are directed upwards and the effective stroke is delivered downwards and forwards.

7. The flipper distinctly acts as a *flexible* screw when making the effective and non-effective strokes.

8. The flipper before making the effective stroke is at right angles to the body and moves towards the body when the effective stroke is given.

9. The angles made by the under surface of the flipper change at every stage of the effective and non-effective strokes.

10. The action of the flippers in the water precisely resembles that of the flippers of the sea-lion.

11. The penguin being deeply submerged when swimming, and its flippers also, the bird can propel itself horizontally along the surface of the water by keeping its body in a horizontal position. If it wishes to dive or fly under the water, it has simply to tilt its body in a downward direction. This act submerges the bird. If it wishes to regain the surface of the water, the body is tilted in an upward direction.

In swimming and diving, the action of the flippers is the same.

12. In diving, the feet are tucked up beneath, and seem to form part of the tail of the bird (Plate clxiii., Fig. 1).

The guillemots in diving do not use their feet ; so that they literally fly under the water. Their wings for this purpose are reduced to the smallest possible dimensions consistent with flight. The loons, on the other hand, while they employ their feet, rarely, if ever, use their wings.

Mr. Macgillivray thus describes a flock of red mergansers which he observed pursuing sand-eels in one of the shallow sandy bays of the Outer Hebrides : "The birds seemed to move under the water with almost as much velocity as in the air, and often rose to breathe at a distance of 200 yards from the spot at which they had dived." [1]

The swimming, diving, and flying movements of the king penguin are depicted at Fig. 1 of Plate clxiii., which follows. At Figs. 2 and 3 of Plate clxiii., the swimming of the extinct bird-like and fish-like reptiles—the plesiosaurus and ichthyosaurus—as restored by the Author, are depicted with great spirit by C. Berjeau.

PLATE CLXIII

Plate clxiii. Life studies of the swimming and diving of the king penguin (*Aptenodytes longirostris*) and post life studies of the plesiosaurus (*P. dolichodeirus*), and ichthyosaurus (*I. communis*) by the Author, specially drawn for the present work by C. Berjeau.

Fig. 1.—Life study by the Author of the swimming and diving or rather flying of the king penguin (*Aptenodytes longirostris*), specially drawn for the present work by C. Berjeau.

The penguin seen to the right of the figure is flying upwards : that at the left is flying downwards : that in the middle has just regained the surface of the water.

Fig. 2.—Study and restoration by the Author and C. Berjeau of the extinct bird-like reptile, the plesiosaurus (*Plesiosaurus dolichodeirus*). This most extraordinary looking creature is characterised by a small bird-like head, teeth resembling those of the crocodile, swan neck, an elongated oval body, and four paddles, flippers, or wing-like structures, namely, two anterior and two posterior. The four flippers are structurally true wings ; that is, they are triangular in shape, elastic, and graduated ; being thickest at the roots and along the anterior margins, and thinnest at the tips and along the posterior margins. The animal, which was an air breather, is supposed to have lived in shallow seas and estuaries and must have been a powerful swimmer. Its flippers

[1] "History of British Birds," vol. i. p. 48.

PLATE CLXIII

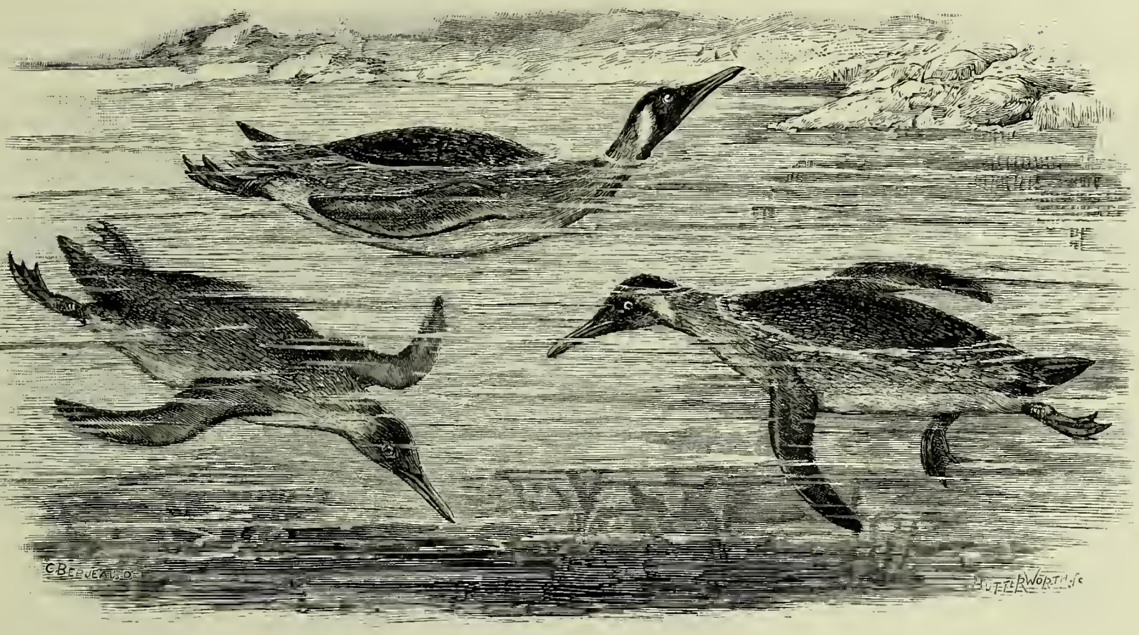


Fig. 1.

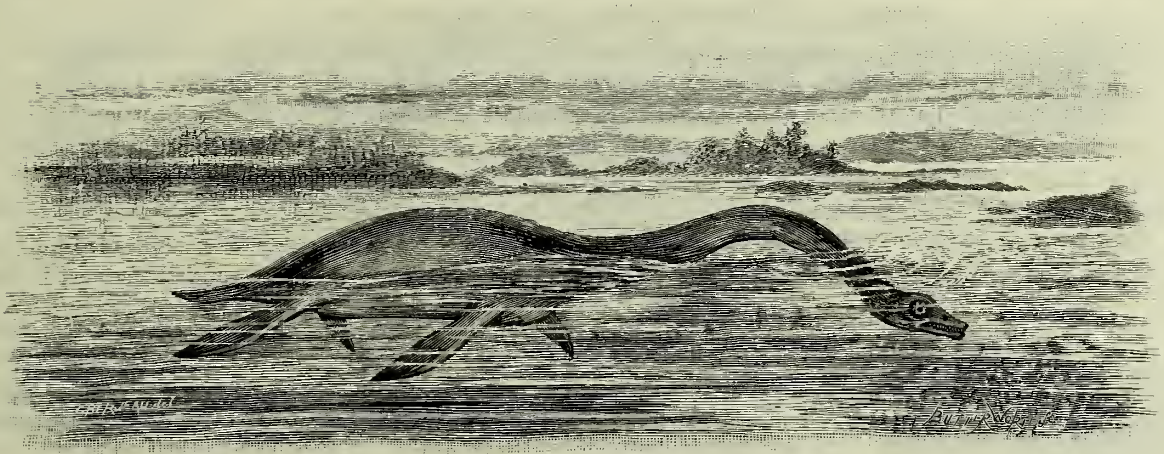


Fig. 2.

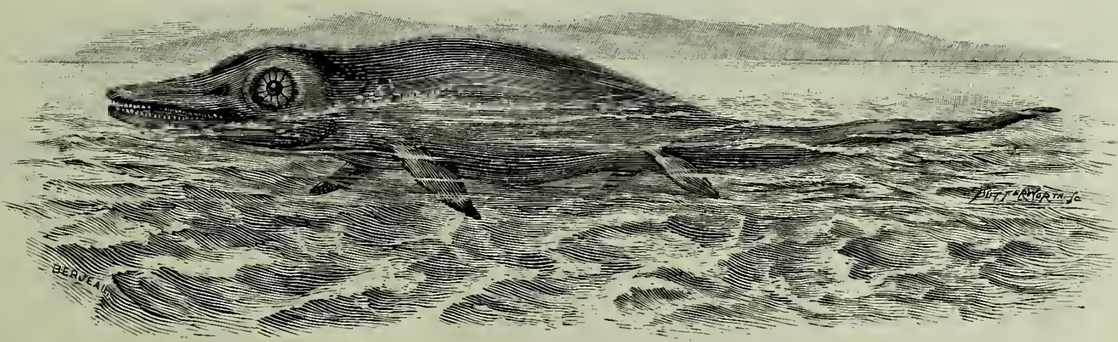


Fig. 3.

PLATE CLXIII (*continued*)

or pseudo-wings may not inaptly be compared to the wings of a dragon-fly. The dragon-fly, as is well known, has four long narrow wings placed at right angles to its body. It is the swiftest of all the insects, and hunts and captures other insects for food. It can readily outfly the swallow, as I can personally testify from observation, and the only bird known to capture it is a small Bulgarian hawk.

There can be little doubt that the plesiosaurus could dive and fly through the water with great rapidity. Its general shape and that of its flippers or wings lead inevitably to this conclusion. It is very interesting to contrast the swimming or flying flippers of the plesiosaurus with the corresponding organs of the ichthyosaurus, sea-lion, penguin, shark, and certain old world fishes.

The skeleton of the plesiosaurus is seen at Plate clxiv., Fig. 2.

Fig. 3.—Study and restoration by the Author and C. Berjeau of the extinct reptile-like fish, the ichthyosaurus (*Ichthyosaurus communis*).

This cadaverous looking animal, which measured over twenty feet in length, has a large reptilian head with prominent staring eyes, a fish-like body, a long tapering tail, believed, till lately, to have had no caudal fin ; and four paddles, flippers or fins—two anterior, and two posterior. Its food consisted of fish and small reptiles.

The flippers or fins resemble those of the plesiosaurus, but they are considerably smaller in size although they have the same structure, and were doubtless useful in paddling the animal forwards. The chief organ of propulsion in the ichthyosaurus as in the crocodile and fish was the long, powerful, tapering tail. From recent finds of the remains of the ichthyosaurus, especially impressions of the skin and soft parts, there are grounds for believing that this striking old world form was provided with what is practically a ridge of dorsal fins and a heterocercal tail, as indicated by the restoration given in Fig. 5, Plate clxiv., by the Author and C. Berjeau.

The skeleton of the ichthyosaurus and one of its paddles or flippers are given at Figs. 3 and 4 of Plate clxiv.

The belief is that the plesiosaurus and ichthyosaurus were air-breathers like the existing Cetacea, examples of which are to be found in the whale and porpoise.

PLATE CLXIV

Plate clxiv. Illustrates some very interesting old world forms. It gives restorations by the Author and C. Berjeau of the extinct bird-like and fish-like reptiles—the plesiosaurus (*Plesiosaurus dolichodeirus*) and ichthyosaurus (*Ichthyosaurus communis*) ; the plesiosaurus attaining to eighteen or twenty feet in length ; the ichthyosaurus, in some cases, measuring as much as twenty-four feet and upwards. It also shows the fine skeletons of those voracious antediluvian types as restored by Conybeare and Cuvier. Lastly, it gives a restoration by H. Woodward, F.R.S., F.G.S., of the seraphim (*Pterygotus anglicus*), a huge extinct crustacean found in the Lower Old Red Sandstone of Perthshire and Forfarshire, Scotland. This great crustacean, called by the Scottish quarrymen the "seraphim," from the wing-like form and feather-like ornament of the thoracic appendages, measured from five to six feet in length, and more than one foot across. The two biggest existing crustaceans are the *Inachus koepferi* (De Haan), a brachyurous or short-tailed crab from Japan—the forearm measuring four feet, the limbs collectively having a spread of twenty-five square feet ; and the *Limulus moluccanus*, the great king crab of China and the Eastern seas, which, when full grown, measures one foot and a half across its carapace, and is three feet in length.

Fig. 1.—Restoration by the Author and C. Berjeau of the plesiosaurus (*Plesiosaurus dolichodeirus*) as seen on land with its flippers, fins, or pseudo-wings spread out. In this position the flippers greatly resemble those of the sea-lion. As already stated the plesiosaurus is supposed to have been an air-breather.

The flippers are, to all intents and purposes, wings structurally and functionally ; that is, they are triangular in shape, elastic, thickest at the roots and along the anterior margins, and thinnest at the tips and along the posterior margins. They resemble the flippers of the sea-lion and the wings of the penguin, and were doubtless powerful propellers. The bones of the flippers are seen at Fig. 2.

Fig. 2.—Representation of the beautiful skeleton of plesiosaurus as restored by Conybeare and Cuvier.

The peculiarities of the skeleton consist in the small bird-like head, the curved elegant vertebral column, the slender continuous and floating ribs, the boat-shaped sternum or breast bone, the curiously modified anterior and posterior extremities and flippers, and their connections with the trunk of the skeleton.

The extremities and flippers are formed on the ordinary vertebrate type, inasmuch as each of the two anterior ones consists of a humerus or arm-bone, a radius and ulna (forearm), a wrist, and five digits ; the digits being composed of a large number of small oblong bones which diminish in size as the tip of the flipper is reached. The two posterior extremities and flippers, in like manner, consist each of a femur or thigh bone, a tibia and fibula (leg), an ankle, and five toes composed of a multiplicity of small oblong bones which taper and become thinner as the tip of the flipper is approached. The bones of the superior and inferior extremities and flippers, where united to the body, are provided with loose rounded ball-and-socket joints ; an arrangement which confers on the extremities and flippers what is virtually universality of motion, similar to what obtains in the wings of birds.

The anterior and posterior extremities and flippers or pseudo-wings of the plesiosaurus are out-riggers, after a fashion, as they are kept well away from the body by the shoulder girdles on the one hand, and the pelvic bones on the other.

Fig. 3.—Flipper of the ichthyosaurus as figured by Professor Owen from a specimen in which not only the bones but also the skin and soft parts of the margins of the flipper were fossilised. The flipper is composed of five rows of small slightly elongated hexagonal bones arranged transversely—each row consisting of fifteen or more bones. The bones of each row fit accurately into each other and form a characteristic pattern. The margins of the flipper were obviously composed of skin, fibrous tissue, and gristle. The flipper was triangular in shape, elastic, and carefully graduated ; being thickest at the root and along the anterior margin (*a*, *b*, *c*), and thinnest along the posterior margin, and at the tip (*d*, *e*, *f*). It was, therefore, a wing-like structure, and resembled anatomically and physiologically the flippers of the plesiosaurus, sea-lion, penguin, and other animals which fly through

PLATE CLXIV

Fig. 1.

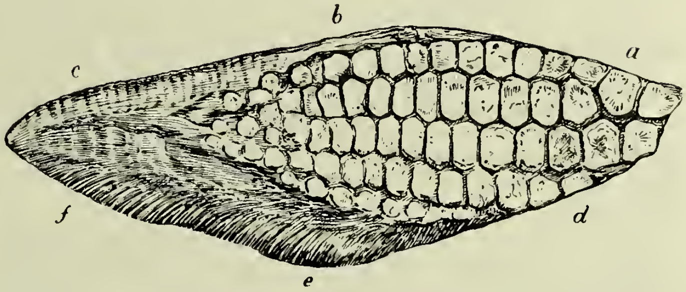


Fig. 3.

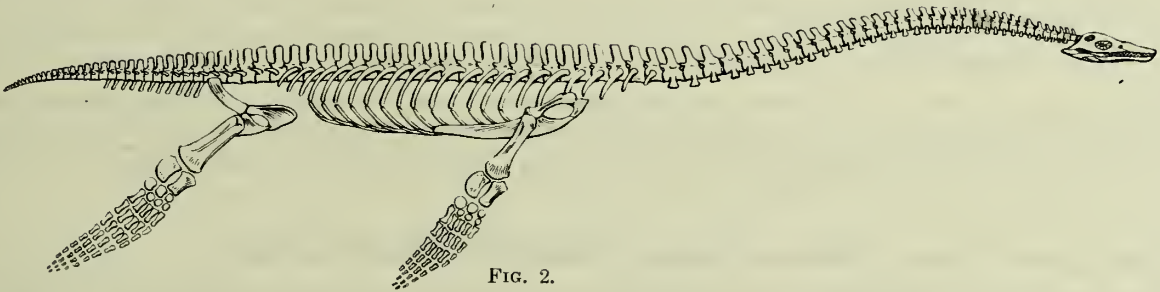


Fig. 2.

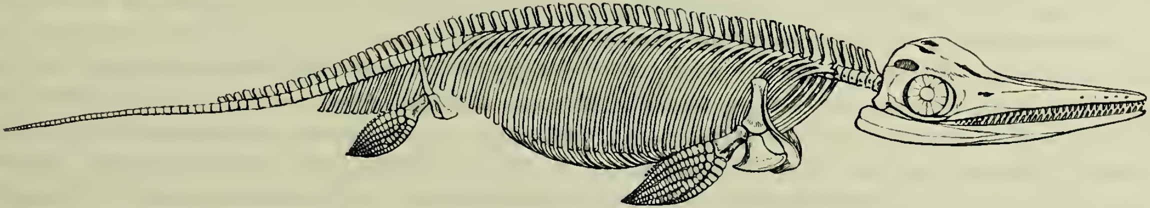


Fig. 4.

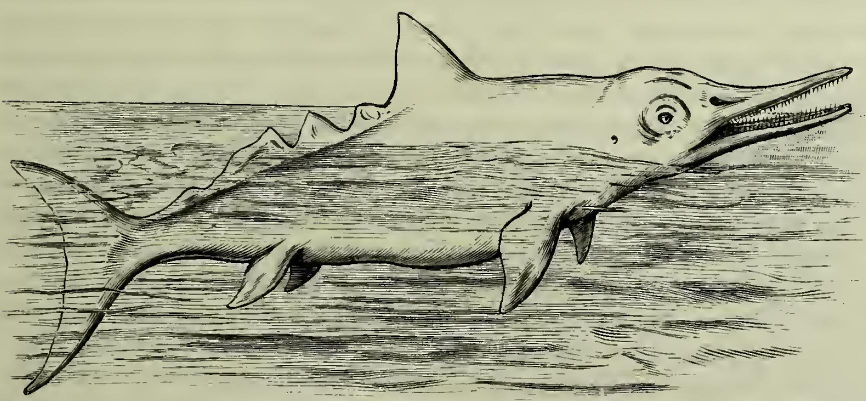


Fig. 5.

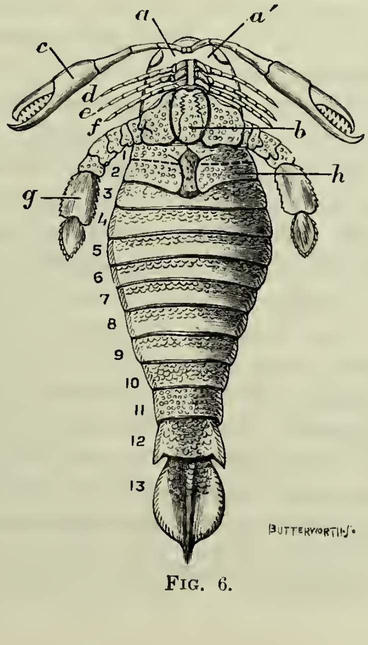


Fig. 6.

PLATE CLXIV (*continued*)

the water. Its size, however, when compared with the size of the body, was small, so that the animal must have relied chiefly on its tail as the organ of propulsion.

Fig. 4.—Skeleton of the ichthyosaurus as restored by Conybeare and Cuvier. The skeleton is very remarkable for its large reptile-like head, with huge eyes in bony shields, formidable teeth proclaiming it a carnivore, its well knit vertebral column tapering backwards with well developed closely set spinous processes, its rather thin numerous continuous and floating ribs which give it a paunchy rotund appearance, its shoulder girdles, pelvic bones, and greatly modified anterior and posterior extremities terminating in digits.

The anterior and posterior extremities and flippers, while considerably altered in general shape, conform, in the main, to the vertebral type as in the case of the plesiosaurus already described (Fig. 2).

The construction of the flippers has been explained under Fig. 3.

The flippers were most probably employed in paddling leisurely along, and in balancing and turning—rapid swimming being secured by the lashing movements of the greatly elongated tail. If the tail, as the latest fossil remains all but prove, was furnished with a caudal fin, its natatory powers must have been very great, and it would be equally as formidable as a swimmer and as a beast of prey.

Fig. 5.—Recent restoration of the ichthyosaurus by the Author and C. Berjean, in which this old world predatory animal is provided with one large well formed and several irregularly-shaped dorsal fins, and a heterocercal caudal or tail fin in addition to its anterior and posterior extremities and flippers. The swimming appliances of the animal are thus greatly increased, and its powers of capturing food much augmented. A large predatory animal like the ichthyosaurus must have required a very ample food supply, and every addition to its swimming power must have been a distinct advantage. In this respect it should be classed with the sharks, which are among the most voracious and swiftest of all known fishes.

Fig. 6.—Ventral aspect of the great crustacean commonly known as the "seraphim" (*Pterygotus anglicus*) found in Forfarshire, Scotland, as restored by H. Woodward. This remarkable extinct form, as already indicated, measured from five to six feet in length and more than one foot in breadth.

It consisted of the following parts :—*a*, *a*, Carapace with large sessile eyes ; *b*, the post oral plate (*metastoma*) serving as a lower lip ; *c*, *c*, chelate appendages (*antennules*) ; *d*, first pair of simple palpi (*antennæ*); *e*, second pair ditto (*mandibles*) ; *f*, third pair ditto (first *maxillæ*) ; *g*, pair of swimming feet with broad basal joints ; their serrated edges acting as *maxillæ* ; *h*, thoracic plate covering the first two thoracic segments (Figs. 1, 2, and dotted line) ; 1 to 6, thoracic segments ; 7 to 12, abdominal segments ; 13, telson or tail-plate.

The swimming feet (*g*, *g*) when compared with the size of the animal are small. Its speed, if it relied exclusively on them, could not, consequently, have been great. It is just possible that it used its telson or tail-plate also in swimming. In escaping from enemies it may even have swum tail first as is the case in the lobster. Its jointed body and powerful muscular system lend countenance to such a belief. (*Vide* the swimming of the lobster as described under Figs. 1 to 6, Plate cliv., p. 1161.)

§ 372. Flight under Water—Difference between Subaqueous and Aerial Flight.

In birds which fly indiscriminately above and beneath the water, the wing is provided with stiff feathers, and reduced to a minimum as regards size. In subaqueous flight the wings may act by themselves, as in the guillemots, or in conjunction with the feet, as in the grebes. To convert the wing into a powerful oar for swimming, it is only necessary to extend and flex it in a slightly backward direction, the mere act of extension causing the feathers to roll down, and giving to the back of the wing, which in this case communicates the more effective stroke, the angle or obliquity necessary for sending the animal forward. This angle, I may observe, corresponds with that made by the foot during extension, so that, if the feet and wings are both employed, they act in harmony. If proof were wanting that it is the back or convex surface of the wing which gives the more effective stroke in subaquatic flight, it would be found in the fact that in the penguin and great auk, which are totally incapable of flying out of the water, the wing is actually twisted round in order that the concave surface, which takes a better hold of the water, may be directed backwards.[1] The thick margin of the wing when giving the effective stroke is turned downwards, as happens in the flippers of the sea-lion, walrus, and turtle. This, I need scarcely remark, is precisely the reverse of what occurs in the ordinary wing in aerial flight. In those extraordinary birds (great auk and penguin) the wing is covered with short, bristly-looking feathers, and is a mere rudiment and semi-rigid ; the movement which wields it emanating, for the most part, from the shoulder, where the articulation partakes of the nature of a universal joint. The wing is beautifully twisted upon itself, and when it is elevated and advanced, it rolls up from the side of the bird at varying degrees of obliquity, till it makes a right angle with the body, when it presents a *narrow* or *cutting edge* to the water. The wing when fully extended, as in ordinary flight, makes, on the contrary, an angle of something like 30° with the horizon. When the wing is depressed and carried backwards, the angles which its under surface make with the surface of the water are gradually increased. The wing of the penguin and auk propels both when it is elevated and depressed. It acts very much after the manner of a screw ; and this, as I shall endeavour to show, holds true likewise of the wing adapted for aerial flight.

The difference between subaquatic flight or diving, and flight proper, may be briefly stated. In aerial flight, the most effective stroke is delivered *downwards* and *forwards* by the under, concave, or biting surface of the wing which is turned in this direction ; the less effective stroke being delivered in an upward and forward direction by

[1] In the swimming of the crocodile, turtle, triton, and frog, the concave surfaces of the feet of the anterior extremities are likewise turned backwards.

the upper, convex, or non-biting surface of the wing. In subaquatic flight, on the contrary, the most effective stroke is delivered *downwards* and *backwards*, the least effective one upwards and forwards. In aerial flight the long axis of the body of the bird and the short axis of the wings are inclined slightly upwards, and make a *forward* angle with the horizon. In subaquatic flight the long axis of the body of the bird and the short axis of the wings are inclined slightly downwards and make a *backward* angle with the surface of the water. The wing acts more or less efficiently in every direction, as the tail of the fish does. The difference noted in the direction of the down stroke in flying and diving, is rendered imperative by the fact that a bird which flies in the air is heavier than the medium it navigates, and must be supported by the wings ; whereas a bird which flies under the water or dives is lighter than the water, and must force itself into it to prevent its being buoyed up to the surface. However paradoxical it may seem, *weight* is necessary to aerial flight, and *levity* to subaquatic flight. A bird destined to fly above the water is provided with travelling surfaces, so fashioned and so applied (they strike *from above, downwards* and *forwards*), that if it was lighter than the air, they would carry it off into space without the possibility of a return ; in other words, the action of the wings would carry the bird obliquely upwards, and render it quite incapable of flying either in a horizontal or a downward direction. In the same way, if a bird destined to fly under the water (auk and penguin) was not lighter than the water, such is the configuration and mode of applying its travelling surfaces (they strike *from above, downwards* and *backwards*), they would carry it in the direction of the bottom without any chance of return to the surface. In aerial flight, weight is the power which nature has placed at the disposal of the bird for regulating its altitude and horizontal movements, a cessation of the play of its wings, aided by the inertia of its trunk, enabling the bird to approach the earth. In subaquatic flight, levity is a power furnished for a similar but opposite purpose ; this, combined with the partial slowing or stopping of the wings and feet, enabling the diving bird to regain the surface at any moment. Levity and weight are auxiliary forces, but they are necessary forces when the habits of the aerial and aquatic birds and the form and mode of applying their travelling surfaces are taken into account. If the aerial flying bird was lighter than the air, its wings would require *to be twisted round* to resemble the diving wings of the penguin and auk. If, on the other hand, the diving bird (penguin or auk) was heavier than the water, its wings would require to resemble aerial wings, and they would require to strike in an opposite direction to that in which they strike normally. From this it follows that *weight* is necessary to the bird (as at present constructed) destined to navigate the air, and *levity* to that destined to navigate the water. If a bird was made very large and very light, it is obvious that the diving force at its disposal would be inadequate to submerge it. If, again, it was made very small and very heavy, it is equally plain that it could not fly. Nature, however, has struck the just balance ; she has made the diving bird, which flies under the water, relatively much heavier than the bird which flies in the air, and has curtailed the travelling surfaces of the former, while she has increased those of the latter. For the same reason, she has furnished the diving bird with a certain degree of buoyancy, and the flying bird with a certain amount of weight—levity tending to bring the one to the surface of the water, weight the other to the surface of the earth, which is the normal position of rest for both. The action of the subaquatic or diving wing of the king penguin is well seen at Plate clxiii., Fig. 1.

From what has been stated it will be evident that the wing acts very differently in and out of the water ; and this is a point deserving of attention, the more especially as it seems to have hitherto escaped observation. In the water the wing, when most effective, strikes *downwards* and *backwards*, and acts as an auxiliary of the foot ; whereas in the air it strikes *downwards* and *forwards*. The oblique surfaces, spiral or otherwise, presented by animals to the water and air are therefore made to act in opposite directions, as far as the down strokes are concerned. This is owing to the greater density of the water as compared with the air,—the former supporting or nearly supporting the animal moving upon or in it ; the latter permitting the creature to fall through it in a downward direction during the ascent of the wing. To counteract the tendency of the bird in motion to fall downwards and forwards, the down stroke is delivered in this direction ; the kite-like action of the wing, and the rapidity with which it is moved, causing the mass of the bird to pursue a more or less horizontal course. I offer this explanation of the action of the wing in and out of the water after repeated and careful observation of tame and wild birds, and, as I am aware, in opposition to all previous writers on the subject.

The rudimentary wings or paddles of the penguin (the movements of which I had an opportunity of studying in a tame specimen) are principally employed in swimming and diving. The feet, which are of moderate size and strongly webbed, are occasionally used as auxiliaries. There is this difference between the movements of the wings and feet of this most curious bird, and it is worthy of attention The wings act together, or synchronously, as in flying birds ; the feet, on the other hand, are moved alternately. The wings are wielded with great energy, and, because of their semi-rigid condition, are incapable of expansion. They therefore present their maximum and minimum of surface by a partial rotation or tilting of the pinion, as in the walrus, sea-lion, and turtle. The feet, which are moved with less vigour, are, on the contrary, rotated or tilted to a very slight extent, the increase and

diminution of surface being secured by the opening and closing of the membranous expansion or web between the toes. In this latter respect they bear a certain analogy to the feet of the seal, the toes of which, as has been explained, spread out or divaricate during extension, and the reverse. The feet of the penguin entirely differ from those of the seal, in being worked separately, the foot of one side being flexed or drawn towards the body, while its fellow is being extended or pushed away from it. The feet, moreover, describe definite curves in opposite directions, the right foot proceeding from within outwards, and from above downwards during extension, or when it is fully expanded and giving the effective stroke; the left one, which is moving at the same time, proceeding from without inwards and from below upwards during flexion, or when it is folded up, as happens during the back stroke. In the acts of extension and flexion the legs are slightly rotated, and the feet more or less tilted. The same movements are seen in the feet of the swan, and in those of swimming birds generally. The curves formed by the feet during extension and flexion produce, when united in the act of swimming, waved lines, these constituting a chart for the movements of the extremities of swimming birds.

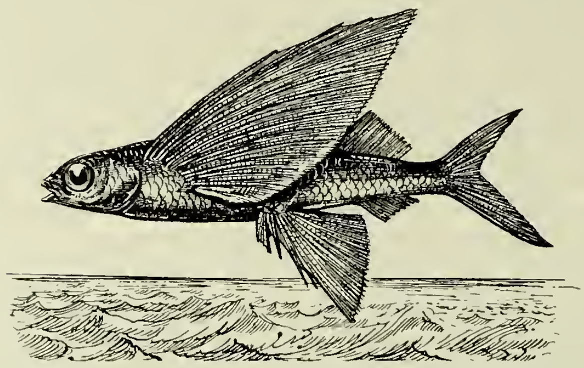


Fig. 503.—The flying-fish, considerably reduced, with wings expanded and elevated in the act of flight. This anomalous and interesting creature is adapted both for swimming and flying. The swimming-tail is consequently retained, and the pectoral fins, which act as wings, are enormously increased in size (the Author).

There is consequently an obvious analogy between the swimming of birds and the walking of man; between the walking of man and the walking of the quadruped; between the walking of the quadruped and the swimming of the walrus, sea-lion, and seal; between the swimming of the seal, whale, dugong, manatee, and porpoise, and that of the fish; and between the swimming of the fish and the flying of the insect, bat, and bird.

The animals which furnish the connecting link between the water and the air are the diving-birds on the one hand, and the flying-fishes on the other,—the former using their wings for flying above an dthrough the water, as occasion demands; the latter sustaining themselves for considerable intervals in the air by means of their enormous pectoral fins.

§ 373. The Flight of the Flying-fish; the Kite-like Action of the Wings, &c.

Whether the flying-fish uses its greatly expanded pectoral fins as a bird its wings, or only as kite-parachutes, has not, so far as I am aware, been determined by actual observation. Most observers are of opinion that these singular creatures glide up the wind, and do not beat it after the manner of birds; so that their flight (or rather leap) is indicated by the arc of a circle, the sea supplying the chord. I have carefully examined the structure, relations, and action of those fins, and am satisfied in my own mind that they act as true pinions, after the manner of gliders, within limits, their inadequate dimensions and limited range alone preventing them from sustaining the fish in the air for considerable periods. When the fins are fully flexed, as happens when the fish is swimming, they are arranged along the sides of the body; but when it takes to the air, they are raised above the body and make a certain angle with it. In being raised they are likewise inclined forwards and outwards, the fins rotating on their long axis until they make an angle of something like 30° with *the horizon*—this being, as nearly as I can determine, the greatest angle made by the wings during the down stroke in the flight of insects and birds.

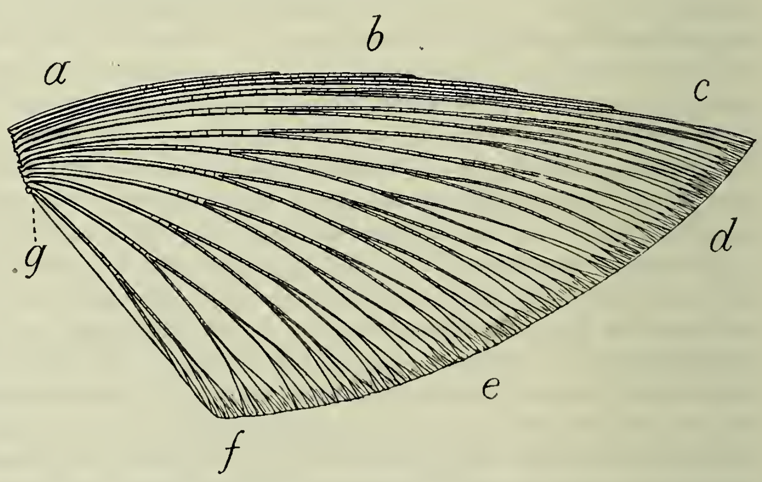


Fig. 504.—Wing of flying-fish expanded and slightly enlarged. *a, b, c*, Anterior margin of wing tapering from the root (*a*) in the direction of the tip (*c*); *d, e, f*, posterior margin of wing tapering from before backwards; *g*, root of wing where it is attached to the body. The tapering is produced by the splitting up of the elastic substance of the wing from within outwards and from before backwards. (Drawn from a specimen in the Author's collection by C. Berjeau.)

The pectoral fins, or pseudo-wings of the flying-fish, like all other wings, act after the manner of kites—the angles of inclination which their under surfaces make with the horizon varying according to the degree of extension, the

speed acquired, and the pressure to which they are subjected by being carried against the air. When the flying-fish, after a preliminary rush through the water (in which it acquires initial velocity), throws itself into the air, it is supported and carried forwards by the kite-like action of its pinions—this action being identical with that of the boy's kite when the boy runs, and by pulling upon the string causes the kite to glide upwards and forwards. In the case of the boy's kite *a pulling force* is applied to the kite in front. In the case of the flying-fish (and everything which flies) *a similar force* is applied from above and behind to the kites formed by the wings by the weight of the flying mass, which always tends to fall vertically downwards. Weight supplies a motor power in flight similar to that supplied by the leads in a clock. In the case of the boy's kite, the hand of the operator furnishes the power; in flight, a large proportion of the power is furnished by the weight of the body of the flying creature. It is a matter of indifference how a kite is flown, so long as its under surface is made to impinge upon the air over which it passes.[1] A kite will fly effectually when it is neither acted upon by the hand nor by a weight, provided always there is a stiff breeze blowing. In flight one of two things is necessary. Either the under surface of the wings must be carried rapidly against still air, or the air must rush violently against the under surface of the expanded but motionless wings. Either the wings, the body bearing them, or the air, must be in rapid motion; one or other must be active. To this there is no exception. To fly a kite in still air the operator must run. If a breeze be blowing the operator does not require to alter his position, the breeze doing the entire work. It is the same with wings. In still air a bird, or whatever attempts to fly, must flap its wings energetically until it acquires initial velocity, when the flapping may be discontinued; or it must throw itself from a height, in which case the initial velocity is acquired by the weight of the body acting upon the inclined planes formed by the motionless wings. The flapping and gliding action of the wings constitutes the difference between ordinary flight and that known as skimming or sailing flight. The flight of the flying-fish is to be regarded rather as an example of the latter than the former, the fish transferring the velocity acquired by the vigorous lashing of its tail in the water to the air—an arrangement which enables it to dispense in a great measure with the flapping of the wings, which act by a combined parachute and wedge action. In the flying-fish the flying fin or wing attacks the air *from beneath*, whilst it is being raised above the body. It has no downward stroke, the position and attachments of the fin preventing it from descending beneath the level of the body of the fish. In this respect the flying fin of the fish differs slightly from the wing of the insect, bat, and bird. The gradual expansion and raising of the fins of the fish, coupled with the fact that the fins never descend below the body, account for the admitted absence of beating, and have no doubt originated the belief that the pectoral fins are merely passive organs. If, however, they do not act as true pinions within the limits prescribed, it is difficult, and indeed impossible, to understand how such small creatures can obtain the momentum necessary to project them a distance of 200 or more yards, and to attain, as they sometimes do, an elevation of twenty or more feet above the water. Mr. Swainson, in crossing the line in 1816, zealously attempted to discover the true action of the fins in question, but the flight of the fish is so rapid that he utterly failed. He gives it as his opinion that flight is performed in two ways—first by a spring or leap, and second by the spreading of the pectoral fins, which are employed in propelling the fish in a forward direction, either by flapping or by a motion analogous to the skimming of swallows. He records the important fact, that the flying-fish can change its course after leaving the water, which satisfactorily proves that the fins are not simply passive structures. Mr. Lord, of the Royal Artillery,[2] thus writes of those remarkable specimens of the finny tribe: "There is no sight more charming than the flight of a shoal of flying-fish, as they shoot forth from the dark green wave in a glittering throng, like silver birds in some gay fairy tale, gleaming brightly in the sunshine, and then, with a mere touch on the crest of the heaving billow, again flitting onward reinvigorated and refreshed."

DESIGN AS WITNESSED IN THE SWIMMING APPLIANCES OF ANIMALS. FINS, FLIPPERS, AND WINGS RESEMBLE EACH OTHER STRUCTURALLY AND FUNCTIONALLY—THE SWIMMING ORGANS FORM THE TRANSITION LINKS BETWEEN THE WALKING AND RUNNING ORGANS AND THE VOLANT OR FLYING ORGANS

As swimming forms the connecting link between walking on the one hand and flying on the other, it will be useful at this stage to direct attention very shortly to the more outstanding features of this form of locomotion. The water presents a yielding fulcrum to the travelling organs of animals acting upon it. As a consequence, all the swimming arrangements are mechanically adapted to meet the peculiar requirements of the case. The travelling

[1] "On the Various Modes of Flight in Relation to Aëronautics," by the Author. (*Proceedings of the Royal Institution of Great Britain*, March 1867.)
[2] *Nature and Art*, November 1866, p. 173.

organs of swimming animals are considerably larger than those employed by animals which walk and run on land. They are, however, very much smaller than those of insects, birds, and bats, which fly in the air.

The water is practically incompressible : the air, on the contrary, being compressible to a high degree—a fact which explains the smaller size and greater rigidity of the flippers and wings of animals which fly in the water as compared with those of animals which fly in the air.

The remarkable thing about the swimming organs of animals is their severe subordination to mechanical principles and the requirements of physics and mathematics. They all reveal in their structure and movements the operation of an intelligent Creator or First Cause. This is especially so in the case of fishes and sea mammals, where the body is ellipsoidal in shape to reduce friction which impedes forward movement, and where the fins and flippers are constructed on a common principle, in which the screw predominates. What is said of the fins and flippers of swimming animals is equally true of the wings of flying animals. As a matter of fact fins, flippers, and wings are screws structurally and functionally. They differ from the ordinary screw propellers employed in navigation in that they do not always revolve in the same direction. On the contrary, they are reversing, reciprocating screw propellers, an arrangement which enables them alternately to seize and let go the water or air on which they operate suddenly, and in such a manner as to secure a maximum of resistance and propelling power with a minimum of slip.

Fins, flippers, and wings are triangular in shape and highly elastic ; the elasticity helping them over their pauses or dead points when the strokes are being reversed. They are thickest at the root where attached to the body, and thinnest at the posterior or free margin. The majority of fins and flippers and of subaquatic and aërial wings are thickest at the root and along the anterior margin, and thinnest at the tip and along the posterior margin. They are beautifully graduated, tapering, elastic structures, and their formation is such that if they are made to vibrate vigorously in the water or the air in a vertical or horizontal direction, they cause the bodies to which they belong to move forward or forward and upward rapidly in a series of alternating complemental curves. During the vibratory to-and-fro movements, the fins, flippers, and wings twist and untwist, and develop in their substance double or figure-of-8 curves which reverse at each new stroke. These curves are primarily due to involuntary effort, and secondarily to the resistance experienced from the water or air by the graduated swimming and flying organs, which yield more at the posterior free margin than at the root. While the movements of the fins, flippers, and wings are always intelligently directed and controlled, they are, to a certain extent, self-acting. Thus, when the propelling organs are made to vibrate in the water or air in a horizontal or vertical direction, they, because of the liquid pressure engendered, reverse and change their planes and angles automatically in virtue of their unequal yielding, their elasticity, and other inherent properties. As a consequence, they develop what is, in reality, a sculling figure-of-8 motion. The figure-of-8 motion is spiral in its nature, and is the best possible for seizing and letting go the water and air at different stages of the to-and-fro movements. All these points can be readily demonstrated by the employment of artificial fish-tails, fins, flippers, and wings, of which I have made a very large number since 1865.

The propelling organs of the higher animals, as indicated, bear a certain analogy to the screw propellers of steamships, with this difference, that in animals the propellers move first in one direction and then in another ; the propellers of ships revolving in only one direction for the time being. It must, however, not be forgotten that the propeller of the steamship has a reciprocating action to the extent that it can be made to rotate and screw in one direction and cause the vessel to forge ahead, and to rotate and screw in another and opposite direction and cause the ship to sail stern first. The graduated, elastic, reciprocating propellers of animals are superior to the continuous, rotatory, rigid propellers of steamships, as I pointed out in a letter to *Engineering* more than thirty years ago. The advantage consists in this : the graduated, elastic, reciprocating propellers of animals make artificial currents for themselves ; every stroke producing a current for each succeeding stroke, with the result that increased abutment and leverage are secured the quicker the animal propeller is driven.

In the screw propeller of the steamship with continuous rotatory motion, on the other hand, increased speed in the propeller often defeats the object in view ; there being a tendency in the ship propeller, when driven at a very high speed, to cut out the water between its blades and to cause it and the propeller to revolve as a solid cylinder, which destroys the screw-action of the propeller so long as the high speed is continued.[1]

In order to test these, and other allied points, I had a small model steamer built on the Clyde (Glasgow), with very fine sailing lines. It was provided with reciprocating engines and all modern appliances. With this I experimented for several years with all kinds of rigid screw propellers ; some having one blade, others two, and others three. I got the best results with the rigid, two-bladed screw propellers. I also tried graduated, elastic, steel screw

[1] If steamship propellers are driven beyond a certain speed their propelling power does not increase in proportion to the speed beyond a given point. In other words, to get from the propellers an additional knot or two per hour an extra consumption of fuel, out of all proportion, is required to obtain the result. This is mainly due to a greatly augmented degree of slip in the propellers. It is also due, though in a less degree, to the increase of friction and resistance experienced by the ship in her accelerated forward motion.

propellers, which regulated their own pitch when they were made to rotate. They did very well, but the gain over the rigid screw propellers was not so great as I anticipated it would be. I obtained the best results from graduated, reciprocating, fish-tail screw propellers constructed of finest steel plates. These were made to vibrate from side to side of the vessel like a fish-tail, and developed quite a remarkable degree of forward speed. They, however, caused a good deal of lateral oscillation in the vessel as she steamed ahead ; a drawback which was only corrected when the fish-tail propellers were made of small dimensions and their number was increased along or in the keel and on either side of the stern of the ship. The multiplication of the fish-tail propellers had its advantages, as it at once increased the speed and steadied the little vessel. It also provided against mishap to any one propeller. The fish-tail propellers were constructed on the type of the caudal fin of the fish. They were more or ess triangular in shape, elastic, and finely graduated; being thickest at the root and thinnest at the posterior free margin. By superposing and increasing the number of plates in the direction of the root of the fish-tail, a perfect gradation could readily be secured. The superposing and graduating of the plates were useful in two ways : (*a*) they secured the precise kind and amount of elasticity required ; and (*b*) they reduced to a minimum the tendency in metals to break off when strained in opposite directions for any considerable period. The tendency to break off is regulated by the suddenness of the bends in opposite directions, and by the number of the reciprocating movements in a given time.

It has been found of late years that if the reciprocating movements do not exceed 800 per minute, steel plates do not crack and break. Beyond this point, and up to 2000 per minute, the tendency for them to give way becomes more and more marked.

The natural fish-tails, flippers, and aquatic flying wings form very effective propellers, and are the highest representatives of the swimming organs of the most highly differentiated aquatic animals.

In the more highly differentiated swimming animals, free use is made of swimming organs which open out or expand during extension and the effective strokes, and close or fold during flexion and the non-effective strokes. The organs also partially rotate on their long axes ; a circumstance which enables them to present narrow, oblique, comparatively non-resisting surfaces and broad, flat, greatly resisting surfaces alternately to the water. Further, concave surfaces are employed during the effective strokes, and convex ones during the non-effective strokes. Lastly, the effective strokes are delivered vigorously and quickly ; the non-effective strokes being made less vigorously and slowly.

The extraordinary modifications in the swimming appliances of animals can only be referred to law, order, and design. The animals so modified are expressly formed to play a definite rôle in the great scheme of nature. When animals of various types become denizens of the water, whether they be invertebrate or vertebrate, whether water breathers or air breathers, whether they produce their young alive or deposit them as spawn in suitable places for hatching out, whether they be cold blooded or warm blooded, whether they are herbivora or carnivora, &c., they all conform more or less closely to the fish-type, both as regards their shape and mode of propulsion. There is nothing in the water itself to account for the general resemblance in shape of the several forms ; still less for the wonderful oneness in structure and function of the swimming organs. If, however, the environment of the swimming animals does not determine and change the shapes of their bodies and travelling organs, we must fall back upon type and original endowment, and on peculiarities inhering in the animals themselves. As such peculiarities cannot be referred to chance, and are obviously the outcome of pre-arrangement, a Creator, Designer, and Upholder becomes a necessity. The peculiarities are the product of development and growth in particular directions to achieve particular results.

The swimming forms and swimming organs had their representatives in early geologic times. They are not, therefore, to be regarded as after thoughts, or the result of accidental changes or accretions extending over practically unlimited periods. If, however, the peculiarities of swimming animals formed part of the original creation, which can scarcely be doubted, there is no room for the operation either of "evolution," "natural selection," or "environment."

Before proceeding to a consideration of the graceful and, in some respects, mysterious evolutions of the denizens of the air, and the far-stretching pinions by which they are produced, it may not be out of place to say a few words in recapitulation regarding the extent and nature of the surfaces by which progression is secured on land and on or in the water. This is the more necessary, as the travelling surfaces employed by animals in walking and swimming bear a certain, if not a fixed, relation to those employed by insects, bats, and birds in flying. On looking back, we are at once struck with the fact, remarkable in some respects, that the travelling surfaces, whether feet, flippers, fins, or pinions, are, as a rule, increased in proportion to the tenuity of the medium on which they are destined to operate. In the ox we behold a ponderous body, slender extremities, and unusually small feet. The feet are slightly expanded in the otter, and considerably so in the ornithorhynchus. The travelling area is augmented

in the seal, sea-lion, penguin, and turtle. In the triton a huge swimming-tail is added to the feet—the tail becoming larger, and the extremities (anterior) diminishing, in the manatee and porpoise, until we arrive at the fish, where not only the tail but *the posterior half of the body* is actively engaged in natation. Turning from the water to the air, we observe a remarkable modification in the huge pectoral fins of the flying-fish, these enabling the creature to take enormous leaps, and serving as pseudo-pinions. Turning in like manner from the earth to the air, we encounter the immense tegumentary expansions of the flying-dragon and galeopithecus, the floating or buoying area of which greatly exceeds that of some of the flying beetles.

In those animals which fly, as insects, birds, and bats, the travelling surfaces, because of the extreme tenuity of the air, are prodigiously augmented ; these in many instances greatly exceeding the actual area of the body. While, therefore, the movements involved in walking, swimming, and flying are to be traced in the first instance to the shortening and lengthening of the muscular, elastic, and other tissues operating on the bones, and their peculiar articular surfaces ; they are to be referred in the second instance to the extent and configuration of the travelling areas—these on all occasions being accurately adapted to the capacity and strength of the animal and the density of the medium on or in which it is intended to progress. Thus the land supplies the resistance, and affords the support necessary to prevent the small feet of land animals from sinking to dangerous depths, while the water, immensely less resisting, furnishes the peculiar medium requisite for buoying the fish, and for exposing, without danger and to most advantage, the large surface contained in its ponderous lashing tail—the air, unseen and unfelt, furnishing that quickly yielding and subtle element in which the greatly expanded pinions of the insect, bat, and bird are made to vibrate with lightning rapidity, discoursing, as they do so, a soft and stirring music very delightful to the lover of nature.

§ 374. General Statement regarding the Nature and Extent of the Surfaces employed in Walking, Swimming, and Flying.

Before entering upon the subject of flight, it may be well if I direct the attention of the reader, very shortly, to the extraordinary disparity which obtains in the size and shape of the travelling organs of animals. I have already explained the peculiarities of the organs of locomotion employed on land, and on and in the water. Those of the air have still to be considered. As flying is more difficult than either swimming or walking, it is necessary at this stage to look backwards as well as forwards. This can best be done by connecting walking and swimming with flying, and by placing in juxtaposition the walking, swimming, and flying organs for careful comparison. No mere description of feet, flippers, fins, and wings can give an adequate idea of their nature and extent. They must be seen side by side and compared with each other and with the bodies to which they belong. I have consequently prepared a series of figures drawn with great care from nature (Plate clxv.), in which the organs for land, water, and air transit are accurately given. The series embraces not only the typical forms adapted for progression on the land, on and in the water, and in the air, but also the transition types which connect land and water transit, and land, water, and air transit.

Strictly speaking, there are only three highways in nature, namely, the land, the water, and the air. There are, however, boggy stretches of land and mud flats which necessitate specially modified organs of locomotion, and there are shallow creeks of water with a semi-aquatic population. The flying dragon and galeopithecus throw themselves from elevated positions into the air, and the flying-fish darts from the azure wave into the thin air above.

In every form of locomotion the travelling organs are specially designed. They are means to ends, and without the means, the ends could not be achieved. No kind of legerdemain, even in the laboratory of nature, and with unlimited time at the disposal of the operator, could convert the small, solid, horny hoofs of the horse into the extensive, exquisitely reticulated, filmy wings of the dragon fly ; and what is true of these extremes is true of everything between them. Every travelling organ works within its own appropriate sphere. It is not a question of evolution, gradation, and modification extending over long periods, but of original endowment and equipment vouchsafed to animals at the outset of their careers. The travelling organs of animals are as necessary to them as their heads or any other part of their bodies.

The travelling organs increase in size according as the medium to be traversed becomes less dense and less resisting. Small feet suffice to support a ponderous body on the land ; a huge swimming tail is required to navigate the water ; and enormously expanded pinions are necessary to support the volant animal in the air. The small feet of quadrupeds would be of no possible use in the air ; the tail of the fish would have no value as apart from water ; and the wings of insects, birds, and bats would wreck themselves if made to beat against the ground. There is a fitness in things. The subjective has its natural objective, and the objective of the travelling organ is the medium on which it was designed to operate from the beginning. The sizes and shapes of the travelling organs

are all pre-determined, as much as the animals to which they belong. All the higher animals would be helpless without their travelling organs. Such important structures had to be provided in advance. They were formed in the body of the parent *in utero,* and had to be trained against the time when food had to be secured and ingested. The animal had not to wait for the development of its organs of propulsion. Without the latter it would have been an imperfect being, and, as such, liable to destruction.

One remarkable feature about the organs of locomotion is their invariable conformity to law and order, and their mechanical completeness. They never err from excess or defect, and they perform the work allotted to them in the most business-like way. They, moreover, all act on a common principle, and are formed on a common pattern.

They form levers of various kinds, and are, as a rule, slightly twisted upon themselves, screw-fashion, in the direction of their length. On the land and in the water they exert a screw and wedge action. In the air they display a screw, wedge, and kite action. From the engineer's point of view they are admirable examples of carefully designed and cunningly fashioned structures. They are integral and important parts of the organic machinery of nature, without which the higher animals would sooner or later inevitably perish.

The nature and extent of the travelling organs of animals carry with them, as few things do, the idea of intelligence and design in their formation. It is impossible to regard the feet, flippers, fins, tails, and wings of animals as chance products, and nothing short of original endowment and the operation of a First Cause can adequately account for their presence.

Environment, desire on the part of animals, use, and habit, are supposed by many to have brought about their origin in some mysterious and unaccountable way. Some trace them to a freak of nature and heredity; others to spontaneous generation and minute chance modifications extending over long periods; others to evolution.

None of the suggested explanations are in the least degree satisfactory. The so-called modifications are so numerous, extensive, and extraordinary, as utterly to set them, one and all, aside. Design, original endowment, bias, and development, and, *arrest of development* in particular directions and to given ends, afford the only clue to the solution of a most involved and difficult problem. Mere environment, chance, desire, use, habit, "heredity," &c., can never account for the amazing adaptations witnessed in the travelling organs of animals, and endless modifications in endless time would avail nothing if the organs were not original creations designed to perform special work in the economy of nature. The travelling organs must have had a beginning. They, moreover, form essential and integral parts of all animals. They must have existed before they could be modified, and on their integrity the life of the individual hangs, as food cannot be obtained without them. It is the merest guessing and speculation to affirm that they are "evolved." Evolved! by what and from what? One can say, and almost certainly say truly, that they are created and designed, and that they grow and develop on lines laid down for them—these lines conducting them to the goal of reasoned achievement and purpose in the mature animal when they have to act as food providers in the wide domain of nature.

The travelling organs cannot be regarded as evolutions pure and simple. Neither can they be considered the product of endless minute modifications in infinite time; they are, strictly speaking, the outcome of original endowment and development in particular directions—the development being, in certain cases, excessive, and in others arrested—and parts which had been formed, suppressed, or reduced to vestiges to meet the peculiar exigencies of land, water, and air transit respectively. If evolution accounted for the growth of the travelling organs, it could not possibly account for the deterioration and disappearance of parts of them. Neither could it account for the obliteration of the general plan which assigns five digits to the extremities of bipeds and quadrupeds. Still less could it account for the increase in size of one bone, as in the cannon bone of the horse, and the deterioration and dwarfing of the other bones of the foot, or for the running together and fusing of the bones of the digits in the wing of the bird. It need scarcely be added that the foot of the horse and the wing of the bird are amongst the most perfect of the travelling organs.

The size and extent of the travelling organs in the higher animals will be readily understood by a reference to Plate clxv.

PLATE CLXV

Plate clxv. illustrates the remarkable disparity which obtains in the size and shape of the travelling organs of animals adapted for land, water, and air transit respectively.

Fig. 1, from A to N inclusive.—Shows typical examples of travelling organs.

A. Foot of the deer. Extreme example of compressed foot for land transit. The ox and the horse furnish other examples.

B. Foot of the otter, slightly webbed. Adapted for land and water transit.

C. Foot of the frog. This foot is expanded and webbed, and is best adapted for water transit (swimming).

PLATE CLXV

FIG. 1.

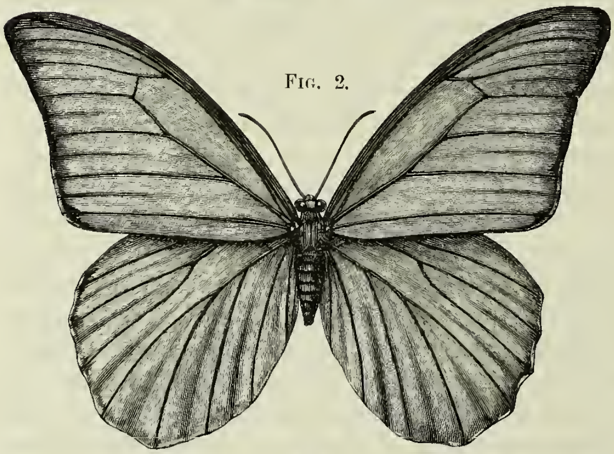


FIG. 2.

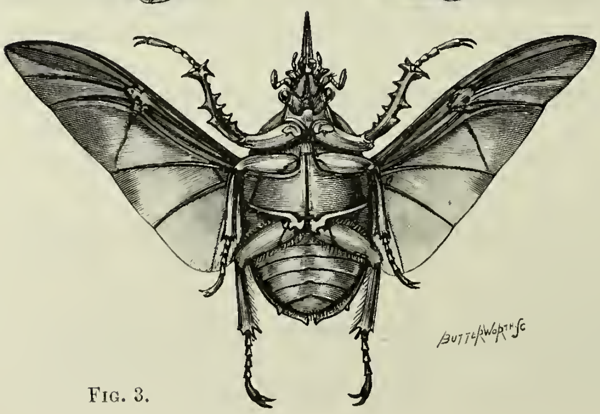


FIG. 3.

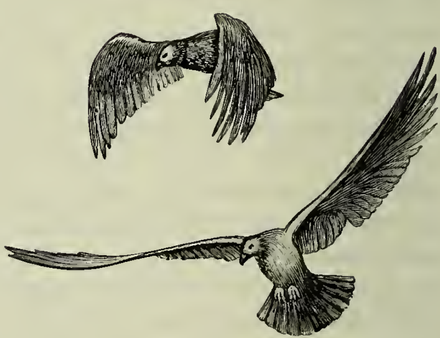


FIG. 6.

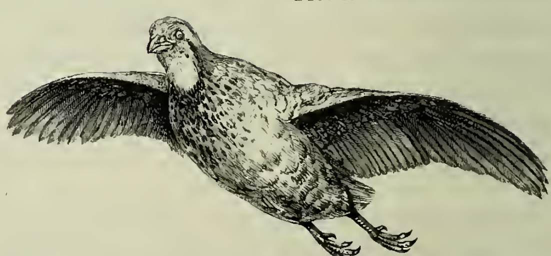


FIG. 4.

FIG. 5.

PLATE CLXV (*continued*)

D. Foot of the ornithorhynchus greatly expanded and webbed and mainly adapted for swimming.

E. Foot of the seal greatly modified, expanded, and webbed. Used almost exclusively for swimming. The seal walks badly on land; it hobbles along by undulatory movements.

F. Swallow with anterior extremities very greatly expanded and clothed with feathers to form wings. The travelling organs in this case when compared with the size and weight of the body are excessively large. They are specially designed to act on the air, which is the thinnest, lightest, and most unstable of the media traversed.

G. The turtle. The anterior and posterior extremities in this case are modified and considerably expanded; the expansion being largely in excess of A, B, C, D, and E, though less than in F. The anterior extremities, moreover, are true wings, in the sense that they are movable, elastic structures which taper and are strongest at the root and anterior margin (*a*, *b*) and thinnest and weakest at the tip and posterior margin (*c*). The posterior extremities (*d*, *e*) are similarly modified, but more resemble feet. They are almost wholly employed in natation.

H. Fish with powerful swimming tail. In the fish nearly half of the body is engaged in natation. The tail is applied to the water laterally or from side to side.

I. The manatee, a fish-shaped, swimming mammal having a large, finely formed, swimming tail. In this case, the tail is applied to the water vertically, or from above downwards. The same holds true of the dugong, porpoise, whale, &c. The vertical movements of the tail enable those remarkable animals readily to reach the surface of the water for breathing purposes.

J. The penguin, a bird adapted almost exclusively for swimming and diving. It has very small, featherless, strong wings, and expanded, webbed feet. The wings are elastic, and taper from the root to the tip, and from the anterior (*a*, *b*) to the posterior (*c*) margin. They yaw and twist screw-fashion in action, and enable the bird to fly and dive in the water with great celerity and in any direction. The feet (*d*) can act independently of the wings, or in concert with them.

K. The flying fish. This singular animal is provided with very large and powerful pectoral fins, resembling wings, which enable it to leave the water and take flights of from two to three hundred yards in the air.

L. The flying lizard. In this case the anterior (*a*) and posterior (*b*) extremities and ribs support a membranous expansion (*c*, *c′*) by the aid of which it flies for considerable distances in a slightly downward curved direction. The membranous expansion is not moved to any great extent by the extremities, and acts mainly as a parachute; the parachute can, however, be controlled within limits.

M. The bat. This quaint little animal has attained to the dignity of flight. As in the flying lemur, its flying membrane (*c*, *c′*) is supported by the anterior (*a*) and posterior (*b*) limbs. The flying membrane of the bat is alternately elevated and depressed with great vigour, as in all flying creatures. This alternate elevation and depression of the flying membrane distinguishes it from the parachute in the ordinary sense. A parachute mainly supports: a wing at once supports and propels (the Author, 1867).

N. The flying lemur. In this instance, the membranous expansion or parachute (*c*, *c′*) is supported by the anterior (*a*) and posterior (*b*) extremities, and tail. This strange animal can all but fly. It glides along by the aid of its parachute from the tops of lofty trees and often for long distances, but always in a slightly downward, curved direction. The anterior and posterior limbs, feet, and tail regulate the tension and angles made by the parachute, which is under control.

FIG. 2.—Butterfly with enormously expanded wings and small body.

FIG. 3.—Goliath beetle with large body and comparatively small wings.

FIG. 4.—Partridge with large, heavy body and small wings.

FIG. 5.—Heron with small, light body and large, powerful wings.

FIG. 6.—Vultures with large heavy bodies and very extensive wings, as seen flexed during the up stroke and fully expanded during the down stroke. The right wing of the lower vulture is twisted upon itself screw-fashion, and reveals two sets of figure-of-8 curves. (Drawn by C. Berjeau for the present work. Figs. 4, 5, and 6 are from photographs.)

PROGRESSION IN OR THROUGH THE AIR

The atmosphere, because of its great tenuity, mobility, and comparative imponderability, presents little resistance to bodies passing through it at low velocities. If, however, the speed be greatly accelerated, the passage of even an ordinary cane is sensibly impeded.

This comes of the action and reaction of matter, the resistance experienced varying according to the density of the atmosphere and the shape, extent, and velocity of the body acting upon it. While, therefore, scarcely any impediment is offered to the progress of an animal in motion, it is often exceedingly difficult to compress the air with sufficient rapidity and energy to convert it into a suitable fulcrum for securing the upward and onward impetus in flight. This arises from the fact that bodies moving in the air experience the *minimum of resistance* and occasion the *maximum of displacement*. Another and very obvious difficulty is traceable to the great disparity in the weight of air as compared with any known solid. This disparity in the case of water is as 1000 to 1. According to the density of the medium so is its buoying or sustaining power.

The Wing a Lever of the Third Order.—To meet the peculiarities stated above, the insect, bat, and bird are furnished with extensive surfaces in the shape of pinions or wings, which they can apply with singular velocity and power, as levers of the third order,[1] at various angles, or by alternate slow and sudden movements, to obtain the necessary degree of resistance and non-resistance. In bats and birds, the degree of resistance and non-resistance is further secured by the opening and closing of the wings. Although the third order of lever is particularly inefficient when the fulcrum is *rigid* and *immobile*, it possesses singular advantages when these conditions are reversed, that

[1] In this form of lever the power is applied between the fulcrum and the weight to be raised. The mass to be elevated is the body of the insect, bat, or bird—the force which resides in the living pinion representing the power, and the air the fulcrum.

is, when the fulcrum, as happens with the air, is *elastic* and *yielding*. In this case a very slight movement at the root of the pinion, or that end of the lever directed towards the body, is succeeded by an immense sweep of the extremity of the wing, where its elevating and propelling power is greatest. This arrangement insures that the large quantity of air necessary for support and propulsion shall be compressed under the most favourable conditions.

It follows from this, that those insects and birds are endowed with the greatest powers of flight the wings of which are the longest. The dragon-fly and albatross furnish examples. The former on some occasions dashes along with amazing velocity and wheels with incredible rapidity ; at other times it suddenly checks its headlong career and hovers or fixes itself in the air after the manner of the kestrel and humming-bird. The flight of the albatross is also remarkable. This magnificent bird sails about with apparent unconcern for hours together, and rarely deigns to flap its enormous pinions, which stream from its body like attenuated kites to the extent, in some cases, of seven feet on either side.

The manner in which the wing levers the body upwards and forwards in flight is shown at Fig. 505.

In this figure, f, f' represent the movable fulcra furnished by the air ; p, p' the power residing in the wing, and b the body to be flown. In order to simplify the problem of flight, I have prolonged the lever formed by the wing beyond the body (b), and have applied to the root of the wing so extended the weight w, w'. x represents the universal joint by which the wing is attached to the body. When the wing ascends, as shown at p, the air ($=$fulcrum f) resists its upward passage, and forces the body (b), or its representative (w), slightly downwards. When the wing descends, as shown at p', the air ($=$fulcrum f') resists its downward passage, and forces the body (b), or its representative (w'), slightly upwards. From this it follows, that when the wing is elevated, the body is depressed, and *vice versâ* ; the wing, especially its tip, describing the arc of a large circle (f, f'), the body (b), or the weights representing it (w, w') describing the arc of a much smaller circle. The body, therefore, as well as the wing, is raised and lowered in flight. When the wing descends it elevates the body, the wing being active and the body passive ; when the body descends it assists in elevating the wing, the body being active and the wing, more or less, passive. The elevator muscles of the wing and the reaction of the air on its under surface all take part in its elevation. It follows, that weight forms a factor in flight, the wing and the weight of the body reciprocating and mutually assisting and relieving each other. This is an argument for employing four wings in artificial flight ; the wings being so arranged that the two which are up shall always by their fall mechanically elevate the two which are down. Such an arrangement is calculated greatly to conserve the driving power, and, as a consequence, to keep down and minimise the weight. It is the upper or dorsal convex surface of the wing which more especially operates upon the air during the up stroke, and the under or ventral concave surface which operates during the down stroke.

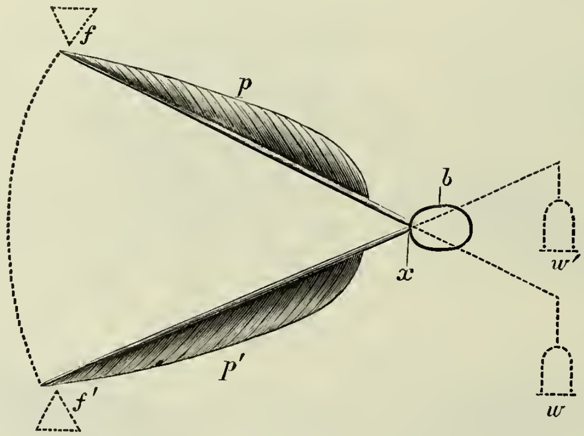


FIG. 505.

In rapid flight, the under concave surface of the wing comes into play *even during the up stroke*, from the fact that the wing during the upward movement makes an upward angle with the horizon—its under surface being carried swiftly forwards and acting as a kite pulled forwards by its string.

The wing, which at the beginning of the down stroke has its surfaces and margins (anterior and posterior) arranged in nearly the same plane with the horizon,[1] rotates upon its anterior margin as an axis during its descent, and causes its under surface to make a gradually increasing angle with the horizon, the posterior margin (Fig. 506, c) in this movement descending beneath the anterior one. A similar but opposite rotation takes place during the up stroke. The rotation referred to causes the wing to twist on its long axis screw-fashion, and to describe a figure-of-8 track in space, one-half of the figure being described during the ascent of the wing, the other half during its descent. The twisting of the wing, and the figure-of-8 track described by it when made to vibrate, are represented at Fig. 506, i, b, j, f. The rotation and twisting of the wing on its long axis as it ascends and descends cause the under surface of the wing to act as a kite, both during the up and down strokes, provided always the body bearing the wing is in forward motion.

[1] In some cases the posterior margin is elevated above the horizon.

§ 375. The Wing can produce and utilise Artificial Air-Currents.

When the wing is thrust upwards, the resistance of the superimposed air causes its posterior thin margin to yield in a downward direction, with the result that the wing, and the body attached to it, fly upwards and forwards in a double curve. It follows, that both the upper and under surfaces of the wing are efficient during the up stroke.

During the down stroke, the under surface only acts. The wing is consequently effective both during its ascent and descent, its slip being nominal in amount. The wing acts as a kite, both when it ascends and descends. It acts more as a propeller than an elevator during its ascent ; and more as an elevator than a propeller during its descent. It is, however, effective both in an upward and downward direction. The efficiency of the wing is greatly increased by the fact that when it ascends it draws a current of air up after it, which current being met by the wing during its descent, greatly augments the power of the down stroke. In like manner, when the wing descends it draws a current of air down after it, which being met by the wing during its ascent, greatly augments the power of the up stroke. These induced currents are to the wing what a stiff autumn breeze is to the boy's kite. The wing is endowed with this very remarkable property, that it creates the current on which it rises and progresses. It literally flies on a whirlwind of its own forming.

These remarks apply more especially to the wings of bats and birds, and those insects whose wings are made to vibrate in a more or less vertical direction. The action of the wing is readily imitated, as a reference to Fig. 506 will show.

If, for example, I take a tapering elastic reed, as represented at *a*, *b*, and supply it with a flexible elastic sail

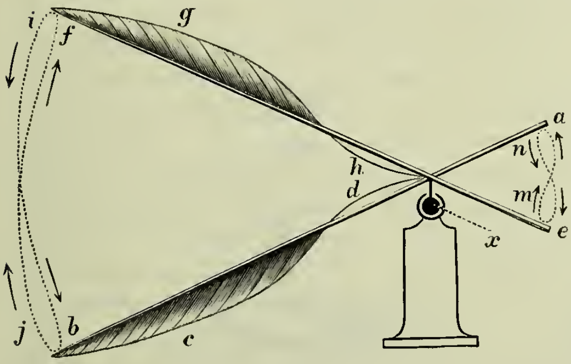


Fig. 506.

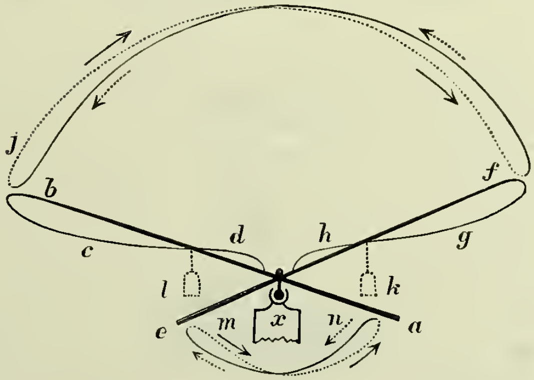


Fig. 507.

(*c*, *d*), and a ball and socket joint (*x*), I have only to seize the reed at *a* and cause it to oscillate upon *x* to elicit all the wing movements. By depressing the root of the reed in the direction *n*, *e*, the wing flies up as a kite in the direction *j*, *f*. During the upward movement the wing flies upwards and forwards, and describes a double curve. By elevating the root of the reed in the direction *m*, *a*, the wing flies down as a kite in the direction *i*, *b*. During the downward movement the wing flies downwards and forwards, and describes a double curve. These curves, when united, form a figure-of-8 track in space. This is what happens in captive flight when the volant animal is prevented from flying forwards. In free flight, when the animal is advancing rapidly, the figure-of-8 made by the wing is gradually opened out and converted into a looped and then a waved trajectory. The figure-of-8 represents the trajectory made by the wing in stationary flight ; the double curve or wave that made in progressive flight.

During the elevation and depression of the wing a large amount of buoyancy and tractile force are evolved, and if the wings and the body of the flying creature are inclined slightly upwards, kite-fashion, as they invariably are in ordinary flight, the whole mass of necessity moves upwards and forwards. To this there is no exception. A sheet of paper or a card will float along if its anterior margin be slightly raised, and if it be projected with sufficient velocity. The wings of all flying creatures when made to vibrate, twist and untwist, the posterior thin margin of each wing twisting round the anterior thick one, like the blade of a screw. The artificial wing represented at Fig. 506 does the same, *c*, *d* twisting round *a*, *b*, and *g*, *h* round *e*, *f*. I have shown how those insects, bats, and birds which flap their wings in a more or less vertical direction evolve tractile or propelling power and buoyancy. I wish now to show that flight may also be produced by a very oblique and almost horizontal stroke of the wing, as in some insects, for example, the wasp, blue-bottle, and other flies. In those insects the wing is made to vibrate with a figure-of-8 sculling motion in a very oblique direction, and with immense energy. This form of flight differs in no respect from the other, unless in the direction of the stroke, and can be readily imitated, as a reference to Fig. 507 will show.

In Fig. 507 the conditions represented at Fig. 506 are exactly reproduced, the only difference being that in the present figure the wing is applied to the air in a more or less horizontal direction, whereas in Fig. 506 it is applied in a more or less vertical direction. The letters in both figures are the same. The insects whose wings tack upon the air in a more or less horizontal direction have an extensive range, each wing describing nearly half a circle, these half circles corresponding to the area of support. The body of the insect is consequently the centre of a circle of motion. When the wing is seized by the hand at *a*, and the root made to travel in the direction *n*, *e*, the tip of the wing travels in the direction *j*, *f*. While so travelling it flies upwards in a double curve, kite-fashion, and elevates the weight *l*. When it reaches the point *f*, it reverses suddenly to prepare for a return stroke, which is produced by causing the root of the wing to travel in the direction *m*, *a*, the tip travelling in the direction *i*, *b*. During the reverse stroke, the wing flies upwards in a double curve, kite-fashion, and elevates the weight *k*. The more rapidly these movements are repeated, the more powerful the wing becomes, and the greater the weight it elevates. This follows because of the reciprocating action of the wing—the wing, as already explained, always drawing a current of air after it during the one stroke, which is met and utilised by it during the next stroke.

The manner in which the artificial air currents are produced by the reciprocating action of the wing will be readily understood by a reference to Fig. 508, which represents transverse sections of a wing constructed on the type of the living wing, being played above three lighted candles (*a*, *b*, *c*).

The wing is made to pass alternately from right to left and from left to right; the plane of the wing occupy-

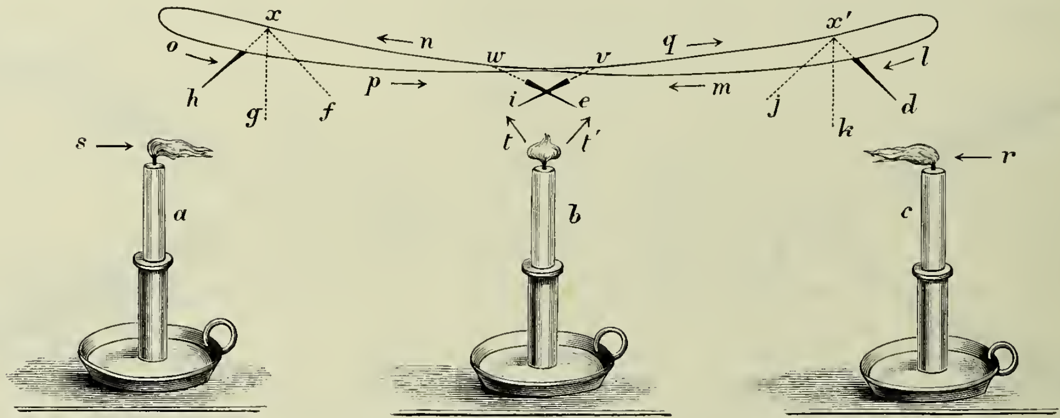


Fig. 508.—Artificial elastic wing being made to vibrate in a horizontal direction above three lighted candles. Wing seen in transverse action (the Author, 1867).

ing a vertical position at the beginning of each stroke, as indicated at *x*, *g* and *x′*, *k*. The moment the wing begins to travel from right to left and encounters air pressure, it assumes an oblique position as shown at *d*. It assumes a more oblique position at *e*, and then a less oblique one at *f*. At *g*, the wing has returned to the vertical, and its movements are slowed to prepare it for making the stroke from left to right. When the wing travels from left to right it assumes successively the positions seen at *h*, *i*, *j*. At *k* the plane of the wing is again in a vertical position. When the wing darts from right to left (*d*, *e*, *f*, *g*), its tip describes a double curve as at *m*, *n*, *x*, *o*, and draws a current of air after it, as indicated at *r* of the lighted candle *c*. When the wing darts from left to right (*h*, *i*, *j*, *k*), its tip describes a complemental and opposite curve as at *p*, *q*, *x′*, *l*, and draws a reverse current after it, as indicated at *s* of the lighted candle *a*. The two currents meet each other and cross at *e*, *i*. The flame of the third lighted candle (*b*) is not now directed from right to left (*r*) and from left to right (*s*) alternately, but away from the operator, in the direction of the tip of the wing, as indicated at *t*, *t′*. The remarkable thing about this experiment is that the graduated, elastic, yielding, artificial wing makes various angles with the horizon and flies backwards and forwards as a true kite: the angles being least when the speed of the wing is greatest, and *vice versâ*. The wing reverses mechanically at the end of each stroke, and the tip of the wing describes a figure-of-8 trajectory in space (*m*, *n*, *o*, *p*, *q*). It goes without saying that the artificial air currents, being met by the wing as it hastens to and fro, very greatly increase the efficiency of the wing as an elevating organ.

The reciprocating action of the natural wing is analogous in all respects to that observed in the flippers of the seal, sea-lion, walrus, and turtle, the swimming wing of the penguin, and the tail of the whale, dugong, manatee, porpoise, and fish. If the muscles of the insect were made to act at the points *a*, *e* of Fig. 507 the body of the insect would be elevated as at *k*, *l*, by the reciprocating action of the wings. The amount of elevating and tractile power developed in the arrangement represented at Fig. 506 can be readily ascertained by fixing a spring or a

weight acting over a pulley to the anterior margin (*a*, *b*, or *e*, *f*) of the wing; weights acting over pulleys being attached to the root of the wing (*a* or *e*).

The amount of elevating power developed in the arrangement represented at Fig. 507 can also be estimated by causing weights acting over pulleys to operate upon the root of the wing (*a* or *e*), and watching how far the weights (*k* or *l*) are raised. In these calculations allowance is of course to be made for friction. The object of the two sets of experiments described and figured, is to show that the wing can exert a tractile power either in a nearly horizontal direction or in a nearly vertical one, flight being produced in both cases. As is well known, a body not supplied with wings or inclined surfaces will, if left to itself, fall vertically downwards. I find, however, that if the body be furnished with wings, its vertical fall is converted into oblique downward flight. This is a very interesting point. Experiment has shown me that a wing when made to vibrate vertically produces horizontal traction plus buoyancy, and that when made to vibrate horizontally, it produces vertical traction plus propulsion. The vertical fall of a body armed with wings produces oblique traction.

§ 376. Weight necessary to Flight.

However paradoxical it may seem, a certain amount of weight is indispensable in flight.

In the first place, it gives peculiar efficacy to the up stroke, by acting upon the under surfaces of the inclined planes formed by the wings in the line of advance. The power and the weight may thus be said to reciprocate; the two sitting, as it were, side by side, and blending their peculiar influences to produce a common result.

Secondly, it adds momentum—a heavy body, when once fairly under weigh, meeting with little resistance from the air, through which it sweeps like a heavy pendulum.

Thirdly, the mere act of rotating the wings on and off the wind during extension and flexion, plus the down stroke, largely represents the exertion on the part of the volant animal, the rest being performed by weight alone.

This last circumstance is deserving of attention, the more especially as it seems to constitute the principal difference between a living flying thing and an aërial machine. If a flying-machine were constructed in accordance with the principles which we behold in nature, the weight and the propelling power of the machine would be made mutually to assist each other. In the aërial machine, as far as yet devised, there is no sympathy between the weight to be elevated and the lifting power, whilst in natural flight the wings and the weight of the flying creature act in concert and reciprocate; the wings elevating the body the one instant, the body by its fall contributing to the elevation of the wings. When the wings elevate the body they are active, the body being passive. When the body assists in elevating the wings it is active, the wings being, in a sense, passive. The force residing in the wings, and the force residing in the body (weight is a force when launched in space and free to fall in a vertical direction) cause the mass of the volant animal to oscillate in vertical curves on either side of an imaginary line—this line corresponding to the path of the insect, bat, or bird in the air. In the flight of insects, bats, and birds, *weight* is to be regarded as an independent moving power, this being made to act upon the oblique surfaces presented by the wings in conjunction with the power expended by the animal—the latter being, by this arrangement, conserved to a remarkable extent. Weight in free flight exerts a constant force, and relieves the elevator and depressor muscles of the wing to a much greater extent than is generally supposed. Weight, assisted by the elastic ligaments or springs, which recover all wings in flexion, is to be regarded as the mechanical expedient resorted to by nature in supplementing the efforts of all flying things.[1] Without this, flight would be of short duration, laboured, and uncertain, and the almost miraculous journeys at present performed by the denizens of the air impossible.

§ 377. Weight contributes to Horizontal Flight.

The area of the insect and bird, when the wings are fully expanded, is, with the single exception of the bats, greater than that of any other class, their weight being proportionally less. It ought, however, never to be forgotten that even the lightest insect or bird is immeasurably heavier than the air, and that there is no fixed relation existing between the weight of body and the expanse of wing in either order. We have thus light-bodied and large-winged insects and birds—as the butterfly, heron, and albatross—and others whose bodies are comparatively heavy, while their wings are insignificantly small—as the sphinx moth and centaur bettle among insects, and the grebe, quail, and partridge among birds. Those apparent inconsistencies in the dimensions of the body and wing are readily explained by the greater muscular development of the heavy-bodied, short-winged insects and birds, and the increased power and rapidity with which the wing in them is made to oscillate. This is of the utmost importance in the

[1] Weight, as is well known, is the sole moving power in the common eight-day clock—the pendulum being used merely to regulate the movements produced by the descent of the leads. In watches, the onus of motion is thrown upon a *spiral spring*; and it is worthy of remark that the mechanician has seized upon, and ingeniously utilised, two forces largely employed in the animal kingdom.

science of aërostation, as showing that flight may be attained by a heavy, powerful animal with comparatively short wings, as well as by a lighter one with enormously enlarged wings. While, therefore, there is apparently no correspondence between the area of the wing and the animal to be raised, there is, unless in the case of sailing birds, an unvarying relation as to the weight and number of oscillations ; so that the problem of flight would seem to resolve itself into one of weight, power, velocity, and small surfaces, *versus* buoyancy, debility, diminished speed, and extensive surfaces—weight in either case being a *sine quâ non.* In order to utilise the air as a means of transit, the body in motion, whether it moves in virtue of the life it possesses, or because of a force superadded, must be heavier than the air. It must tread and rise upon the air as a swimmer upon the water, or as a kite upon the wind. This is necessary for the simple reason that the body must be active, the air passive. It must act against gravity, and elevate and carry itself forward at the expense of the air and of the force which resides in the body. If it were otherwise—if it were rescued from the law of gravity on the one hand, and bereft of independent movement on the other—it would float about uncontrolled and uncontrollable, as happens in the ordinary gas-balloon.

That the weight of the body plays an important part in the production of flight may be proved by a very simple experiment (Fig. 509), originally made by me in 1870.

If I take two primary feathers and fix them in an ordinary cork, as in Fig. 509, and allow the apparatus to drop from a height, I find the cork does not fall vertically downwards, but *downwards* and *forwards* in a curve. This follows, because the feathers *a*, *b* are twisted, flexible, inclined planes, which arch in an upward direction. They are, in fact, true wings in the sense that an insect wing in one piece is a true wing. When dragged downwards by the cork (*c*), which would, if left to itself, fall vertically, they have what is virtually a down stroke communicated to them. Under these circumstances a struggle ensues between the cork tending to fall vertically and the feathers tending to travel in an upward direction, and, as a consequence, the apparatus describes the curve *d*, *e*, *f*, *g* before reaching the earth *h*, *i*. This is due to the action and reaction of the feathers and air upon each other, and to the influence which gravity exerts upon the cork. The forward travel of the cork and feathers, as compared with the space through which they fall, is very great. Thus, in some instances, I found they advanced as much as a yard and a half in a descent of three yards. Here, then, is an example of flight produced by purely mechanical appliances. Certain of the winged seeds fly in precisely the same manner. The seeds of the plane-tree have, for example, two wings which exactly resemble the wings employed for flying ; thus they taper from the root towards the tip, and from the anterior margin towards the posterior margin, the margins being twisted and disposed in different planes to form true screws. This arrangement prevents the seed from falling rapidly or vertically, and if a breeze be blowing it is wafted to a considerable distance before it reaches the ground. Nature is uniform and consistent throughout. She employs the same principle, and very nearly the same means, for flying a heavy, solid seed which she employs for flying an insect, a bat, or a bird.

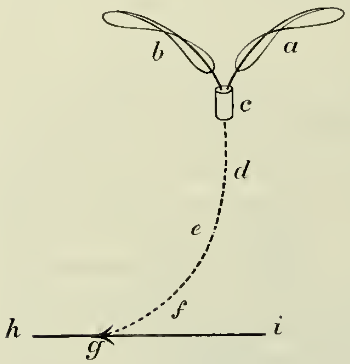


Fig. 509.

When artificial wings constructed on the plan of natural ones, with stiff roots, tapering, semi-rigid, anterior margins, and thin, yielding, posterior margins, are allowed to drop from a height, they describe double curves in falling, the roots of the wings reaching the ground first. This circumstance proves the greater buoying power of the tips of the wings as compared with the roots. I might refer to many other experiments made in this direction, but these are sufficient to show that weight, when acting upon wings, or, what is the same thing, upon tapering, elastic, twisted inclined planes, must be regarded as an independent moving power. But for this circumstance flight would be at once the most awkward and laborious form of locomotion, whereas in reality it is incomparably the easiest and most graceful. The power which rapidly vibrating wings have in sustaining a body which tends to fall vertically downwards, is much greater than one would naturally imagine, from the fact that the body, which *is always beginning to fall*, is never permitted actually to do so. Thus, when it has fallen sufficiently far to assist in elevating the wings, it is at once elevated by the vigorous descent of those organs. The body consequently never acquires the downward momentum which it would do if permitted to fall through a considerable space uninterruptedly. It is easy to restrain even a heavy body when beginning to fall, while it is very difficult to check its progress when it is once fairly launched in space and travelling rapidly in a downward direction.

§ 378. Weight, Momentum, and Power as Factors in Flight.

When a bird rises it has little or no momentum, so that if it comes in contact with a solid resisting surface it does not injure itself. When, however, it has acquired all the momentum of which it is capable, and is in full

and rapid flight, such contact results in destruction. My late friend, Mr. A. D. Bartlett, informed me of an instance where a wild duck terminated its career by coming violently in contact with one of the glasses of the Eddystone Lighthouse. The glass, which was fully an inch in thickness, was completely smashed. Advantage is taken of this circumstance in killing gannets, a bait being placed on a board, and set afloat with a view to breaking the neck of the bird when it swoops down with closed wings to seize the coveted food. The increase of power due to momentum in heavy bodies in motion is well illustrated in the start and progress of steamboats. In these the *slip*, as it is technically called, decreases as the speed of the vessel increases ; the strength of two or three men, if applied by a hawser attached to the stern of a moderate-sized vessel, being sufficient to retard, and, in some instances prevent, its starting. In such a case the power of the engine is almost entirely devoted to "slip," or in giving motion to the fluid in which the screw or paddle is immersed. It is consequently not the power residing in the paddle or screw which is cumulative, but the momentum inhering in the mass. In the bird, the momentum, *alias* weight, is made to act upon the inclined planes formed by the wings, these adroitly converting it into sustaining and propelling power. It is to this circumstance, more than any other, that the prolonged flight of birds is mainly due, the inertia or dead weight of the trunk aiding and abetting the action of the wings, and so relieving the excess of exertion which would necessarily devolve on the bird. It is thus that the power which in living structures resides in the mass is conserved, and the mass itself turned to account. But for this reciprocity, no bird could retain its position in the air for more than a few minutes at a time. This is proved by the comparatively brief upward flight of the lark and the hovering of the hawk when hunting. In both these cases the body is exclusively sustained by the action of the wings, the weight of the trunk taking no part in it ; in other words, the weight of the body does not contribute to flight by adding its momentum and the impulse which momentum begets. In the flight of the albatross, on the other hand, the momentum acquired by the moving mass does the principal portion of the work, the wings for the most part being simply rotated on and off the wind to supply the kite-surfaces and angles necessary for the inertia or mass to operate upon. It appears to me that in this blending of active and passive power the mystery of flight is concealed, and that no arrangement will succeed in producing artificial flight which does not recognise and apply the principle here pointed out.

§ 379. Air-cells in Insects, Birds, and Bats not necessary to Flight.

The boasted levity of insects, birds, and bats, concerning which so much has been written by authors in their attempts to explain flight, is delusive in the highest degree.

Insects, birds, and bats are as heavy, bulk for bulk, as most other living creatures, and flight can be performed perfectly by animals which have neither air-sacs nor hollow bones ; air-sacs being found in animals never designed to fly. Those who subscribe to the heated-air theory are of opinion that the air contained in the cavities of insects and birds is so much lighter than the surrounding atmosphere, that it must of necessity contribute materially to flight. I may mention, however, that the quantity of air imprisoned is, to begin with, so infinitesimally small, and the difference in weight which it experiences by increase of temperature so inappreciable, that it ought not to be taken into account by any one endeavouring to solve the difficult and important problem of flight. The Montgolfier or fire-balloons were constructed on the heated-air principle ; but as these have no analogues in nature, and are apparently incapable of improvement, they are mentioned here rather to expose what I regard as a false theory than as tending to elucidate the true principles of flight.

When we have said that cylinders and hollow chambers increase the area of the insect and bird, and that an insect and bird so constructed is stronger, weight for weight, than one composed of solid matter, we may dismiss the subject ; flight being, as I shall endeavour to show by-and-by, not so much a question of levity as one of weight and power intelligently directed, upon properly constructed flying surfaces.

The bodies of insects, birds, and bats are constructed on strictly mechanical principles—lightness, strength, and durability of frame being combined with power, rapidity, and precision of action. The cylindrical method of construction is in them carried to an extreme, the bodies and legs of insects displaying numerous unoccupied spaces, while the muscles and solid parts are tunnelled by innumerable air-tubes, which communicate with the surrounding medium by a series of apertures termed spiracles.

A somewhat similar disposition of parts is met with in birds, these being in many cases furnished not only with hollow bones, but also (especially the aquatic ones) with a liberal supply of air-sacs. They are likewise provided with a dense covering of feathers or down, which adds greatly to their bulk without materially increasing their weight. Their bodies, moreover, in not a few instances, particularly in birds of prey, are more or less flattened. The air-sacs are well seen in the swan, goose, and duck ; and I have on several occasions minutely examined them with a view to determine their extent and function. In two of the specimens which I injected, the material

employed had found its way not only into those usually described, but also into others which ramify in the substance of the muscles, particularly the pectorals. No satisfactory explanation of the purpose served by these air-sacs has, I regret to say, been yet tendered. According to Sappey,[1] who has devoted a large share of attention to the subject, they consist of a membrane which is neither serous nor mucous, but partly the one and partly the other; and as blood-vessels in considerable numbers, as my preparations show, ramify in their substance, and they are in many cases covered with muscular fibres which confer on them a rhythmic movement, some recent observers (Mr. Drosier [2] of Cambridge, for example) have endeavoured to prove that they are adjuncts of the lungs, and therefore assist in aërating the blood. This opinion was advocated by the celebrated John Hunter as early as 1774,[3] and is probably correct, since the temperature of birds is higher than that of any other class of animals, and because they are obliged occasionally to make great muscular exertions both in swimming and flying. Others have viewed the air-sacs in connection with the hollow bones frequently, though not always, found in birds,[4] and have come to look upon the heated air which they contain as being more or less essential to flight. That the air-cells have absolutely nothing to do with flight is proved by the fact that some excellent fliers (take the bats, for example) are destitute of them, while birds such as the ostrich and apteryx, which are incapable of flying, are provided with them. Analogous air-sacs, moreover, are met with in animals never intended to fly; and of these I may instance the great air-sac occupying the cervical and axillary regions of the orang-outang, the float or swimming-bladder in fishes, and the pouch communicating with the trachea of the emu.[5]

The same may be said of the hollow bones—some really admirable fliers, as the swifts, martins, and snipes, having their bones filled with marrow, while those of the wingless running birds alluded to have air. Furthermore and finally, a living bird weighing 10 lbs. weighs the same when dead, plus a very few grains; and all know what effect a few grains of heated air would have in raising a weight of 10 lbs. from the ground.

§ 380. How Balancing is effected in Flight, the Sound produced by the Wing, &c.

The manner in which insects, birds, and bats balance themselves in the air has hitherto, and with reason, been regarded as a mystery, for it is difficult to understand how they maintain their equilibrium when the wings are beneath their bodies. In the bird and bat, where the stroke is delivered more vertically than in the insect, the *basis of support* is increased by the tip of the wing folding inwards and backwards in a more or less horizontal direction at the end of the down stroke; and outwards and forwards at the end of the up stroke. This is accompanied by the rotation of the outer portion of the wing upon the wrist as a centre, the tip of the wing, because of the ever-varying position of the wrist, describing an ellipse. In insects whose wings are broad and large (butterflies), and which are driven at a comparatively low speed, the balancing power is diminished. In insects whose wings, on the contrary, are long and narrow (blow-flies), and which are driven at a high speed, the balancing power is increased. It is the same with short and long-winged birds, so that the function of balancing is in some measure due to the form of the wing, and the speed with which it is driven; the long wing and the wing made to vibrate with great energy increasing the capacity for balancing. When the body is light and the wings very ample (butterfly and heron), the reaction elicited by the ascent and descent of the wings displaces the body to a marked extent. When, on the other hand, the wings are small and the body large, the reaction produced by the vibration of the wing is scarcely perceptible. Apart, however, from the shape and dimensions of the wing, and the rapidity with which it is urged, it must never be overlooked that all wings (as has been pointed out) are attached to the bodies of the animals bearing them by some form of universal joint, and in such a manner that the bodies, whatever the position of the wings, are accurately balanced, and swim about in a more or less horizontal position, like a compass set upon gimbals. To such an extent is this true, that the position of the wing is a matter of indifference. Thus the pinion may be above, beneath, or on a level with the body; or it may be directed forwards, backwards, or at right angles to the body. In either case the body is balanced mechanically and without effort. To prove this point I made

[1] Sappy enumerates fifteen air-sacs—the *thoracic*, situated at the lower part of the neck, behind the sternum; *two cervical*, which run the whole length of the neck to the head, which they supply with air; *two pairs of anterior*, and *two pairs of posterior diaphragmatic*; and *two pairs of abdominal*.

[2] "On the Functions of the Air-cells and the Mechanism of Respiration in Birds," by W. H. Drosier, M.D., Caius College. (*Proc. Camb. Phil. Soc.*, Feb. 12, 1866.)

[3] "An Account of certain Receptacles of Air in Birds which communicate with the Lungs, and are lodged among the Fleshy Parts and in the Hollow Bones of these Animals." (*Phil. Trans.*, London, 1774.)

[4] According to Dr. Crisp, the swallow, martin, snipe, and many birds of passage have no air in their bones (*Proc. Zool. Soc.*, London, part xxv. 1857, p. 13). The same author, in a second communication (pp. 215 and 216), adds that the glossy starling, spotted fly-catcher, whinchat, wood-wren, willow-wren, black-headed bunting, and canary, five of which are birds of passage, have likewise no air in their bones. The following is Dr. Crisp's summary: Out of ninety-two birds examined he found "air in many of the bones, five (*Falconidæ*): air in the humeri and not in the inferior extremities, thirty-nine; no air in the extremities and probably none in the other bones, forty-eight."

[5] Nearly allied to this is the great gular pouch of the bustard. Specimens of the air-sac in the orang, emu, and bustard, and likewise of the air-sacs of the swan and goose, as prepared by me, may be seen in the Museum of the Royal College of Surgeons of England, London.

an artificial bird, taking care to unite the roots of the wings to the upper part of the body by means of universal joints. I found, as I had anticipated, that in whatever position the wings were placed, whether above, beneath, or on a level with the body, or on either side of it, the body almost instantly attained a position of rest. The body was, in fact, equally suspended and balanced from all points.

§ 381. Rapidity of Wing Movements partly accounted for.

Much surprise has been expressed at the enormous rapidity with which some wings are made to vibrate. The wing of the insect is, as a rule, very long and narrow. As a consequence, a comparatively slow and very limited movement at the root confers great range and immense speed at the tip; the speed of each portion of the wing increasing as the root of the wing is receded from. This is explained on a principle well understood in mechanics, namely, that when a rod hinged at one end is made to move in a circle, the tip or free end of the rod describes a much wider circle *in a given time* than a portion of the rod nearer the hinge. This principle is illustrated at Fig. 510. Thus if a, b of Fig. 510 be made to represent the rod hinged at x, it travels through the space d, b, f in the same time it travels through j, k, l; and through j, k, l in the same time it travels through g, h, i; and through g, h, i in the same time it travels through e, a, c, which is the area occupied by the thorax of the insect. If, however, the part of the rod b travels through the space d, b, f in the same time that the part a travels through the space e, a, c, it follows of necessity that the portion of the rod marked a moves very much slower than that marked b.[1]

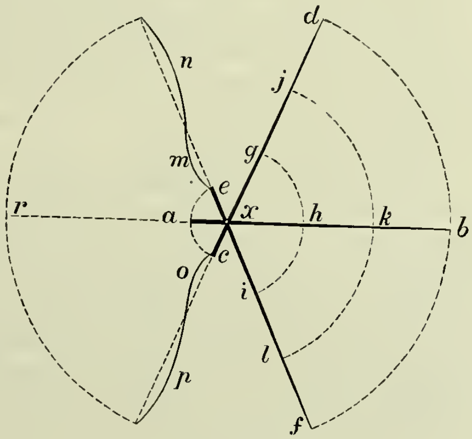


FIG. 510.

The muscles of the wing of the insect are applied at the point a, as short levers (the point referred to corresponding to the thorax of the insect), so that a comparatively slow and limited movement at the root of the wing produces the marvellous speed observed at the tip; the tip and body of the wing being those portions which occasion the blur or impression produced on the eye by the rapidly oscillating pinion. But for this mode of augmenting the speed originally inaugurated by the muscular system, it is difficult to comprehend how the wings could be driven at the velocity attributed to them. The wing of the blow-fly is said to make 300 strokes per second, that is, 18,000 per minute. Now it appears to me that muscles to contract at the rate of 18,000 times in the minute would be exhausted in a very few seconds, a state of matters which would render the continuous flight of insects impossible. (The heart contracts generally between sixty and seventy times in a minute.) I am, therefore, disposed to believe that the number of contractions made by the thoracic muscles of insects has been greatly overstated; the high speed at which the wing is made to vibrate being due less to the separate and sudden contractions of the muscles at its root than to the fact that the speed of the different parts of the wing is increased in a direct ratio as the several parts are removed from the driving point, as already explained. Speed is certainly a matter of great importance in wing movements, as the elevating and propelling power of the pinion depends to a great extent upon the rapidity with which it is urged. Speed, however, may be produced in two ways—either by a series of separate and opposite movements, such as is witnessed in the action of a piston, or by a series of separate and opposite movements acting upon an instrument so designed, that a movement applied at one part increases in rapidity as the point of contact is receded from, as happens in the wing. In the piston movement the motion is uniform, or nearly so; all parts of the piston travelling at the same speed. In the wing movements, on the contrary, the motion is gradually accelerated towards the tip of the pinion, where the pinion is most effective as an elevator and propeller, and decreased towards the root, where it is least effective—an arrangement calculated to reduce the number of muscular contractions, while it contributes to the actual power of the wing. This hypothesis, it will be observed, guarantees to the wing a very high speed, with comparatively few reversals and comparatively few muscular contractions.

In the bat and bird the wings do not vibrate with the same rapidity as in the insect, and this is accounted for by the circumstance, that in them the muscles do not act exclusively at the root of the wing. In the bat and bird

[1] In this diagram I have purposely represented the right wing by a straight *rigid* rod. The natural wing, however, is curved, *flexible*, and *elastic*. It likewise *moves in curves*, the curves being most marked towards the end of the up and down strokes, as shown at m, n, o, p. The curves, which are double figure-of-8 curves, are obliterated towards the middle of the strokes (a, r). This remark holds true of all natural wings, and of all artificial wings properly constructed. The curves and the reversal thereof are necessary to give continuity of motion to the wing during its vibrations, and, what is not less important, to enable the wing alternately to seize and dismiss the air.

the muscles run along the wing towards the tip for the purpose of flexing or folding the wing prior to the up stroke, and for opening out and expanding it prior to the down stroke.

As the wing must be folded or flexed and opened out or expanded every time it is elevated and depressed, and as the muscles producing flexion and extension are long muscles with long tendons, which act at long distances as long levers, and comparatively slowly, it follows that the great short muscles (pectorals, &c.) situated at the root of the wing must act slowly likewise, as the muscles of the thorax and wing of necessity act together to produce one pulsation or vibration of the wing. What the wing of the bat and bird loses in speed it gains in power, the muscles of the bat's and bird's wing acting directly upon the points to be moved, and under the most favourable conditions. In the insect, on the contrary, the muscles act indirectly, and consequently at a disadvantage. If the pectorals only moved, they would act as short levers, and confer on the wing of the bat and bird the rapidity peculiar to the wing of the insect.

The tones emitted by the bird's wing would in this case be heightened. The wings of the swan in flying produce a loud whistling sound, and those of the pheasant, partridge, and grouse a sharp whirring noise like the stone of a knife-grinder.

It is a mistake to suppose, as many do, that the tone or note produced by the wing during its vibrations is a true indication of the number of beats made by it in any given time. This will be at once understood when I state, that a long wing will produce a higher note than a shorter one driven at the same speed and having the same superficial area, from the fact that the tip and body of the long wing will move through a greater space in a given time than the tip and body of the shorter wing. This is occasioned by all wings being joined at their roots, the sweep made by the different parts of the wing in a given time being longer or shorter in proportion to the length of the pinion. It ought, moreover, not to be overlooked, that in insects the notes produced are not always referable to the action of the wings, these, in many cases, being traceable to movements induced in the legs and other parts of the body.

It is a curious circumstance, that if portions be removed from the posterior margins of the wings of a buzzing insect, such as the wasp, bee, blue-bottle, fly, &c., the note produced by the vibration of the pinions is raised in pitch. This is explained by the fact, that an insect whose wings are curtailed requires to drive them at a much higher speed in order to sustain itself in the air. That the velocity at which the wing is urged is instrumental in causing the sound, is proved by the fact, that in slow-flying insects and birds no note is produced ; whereas in those which urge the wing at a high speed, a note is elicited which corresponds within certain limits to the number of vibrations and the form of the wing. It is the posterior or thin, flexible margin of the wing which is more especially engaged in producing the sound ; and if this be removed, or if this portion of the wing, as is the case in the bat and owl, be constructed of very soft materials, the character of the note is altered. An artificial wing, if properly constructed and impelled at a sufficiently high speed, emits a drumming noise which closely resembles the note produced by the vibration of short-winged, heavy-bodied birds, all which goes to prove that sound is a concomitant of rapidly vibrating wings.

§ 382. The Wing Area Variable and in Excess.

The travelling surfaces of insects, bats, and birds engaged in flight greatly exceed those of fishes and swimming animals ; the travelling surfaces of swimming animals being greatly in excess of those of animals which walk and run. The wing area of insects, bats, and birds varies very considerably, flight being possible within a comparatively wide range. Thus there are light-bodied and large-winged insects and birds—as the butterfly (Fig. 2, Plate clxv., p. 1198) ; and others whose bodies are comparatively heavy, while their wings are insignificantly small—as the sphinx moth and Goliath beetle (Fig. 3, Plate clxv.) among insects, and the grebe, quail, and partridge (Fig. 4, Plate clxv.) among birds.

The apparent inconsistencies in the dimensions of the body and wings are readily explained by the greater muscular development of the heavy-bodied, short-winged insects and birds, and the increased power and rapidity with which the wings in them are made to oscillate. In large-winged animals the movements are slow ; in small-winged ones comparatively very rapid. This shows that flight may be attained by a heavy, powerful animal with comparatively small wings, as well as by a lighter one with enormously enlarged wings. While there is apparently no fixed relation between the area of the wings and the animal to be raised, there is, unless in the case of sailing birds,[1]

[1] In birds which skim, sail, or glide, the pinion is greatly elongated or ribbon-shaped, and the weight of the body is made to operate upon the inclined planes formed by the wings in such a manner that the bird, when it has once got fairly under way, is in a measure self-supporting. This is especially the case when it is proceeding against a slight breeze—the wind and the inclined planes resulting from the upward inclination of the wings reacting upon each other, with this very remarkable result, that the mass of the bird moves steadily forwards in a more or less horizontal direction.

an unvarying relation between the weight of the animal, the area of its wings, and the number of oscillations made by them in a given time.

Perhaps the best examples of a heavy-bodied, small-winged and a moderately heavy, large-winged bird that can be adduced are afforded by the diver and grey gull respectively. I happened to obtain fresh specimens of these two birds on the same day, and found, curiously enough, that each weighed exactly two pounds. The disparity (and it was very striking) was chiefly observable in the wings; the wings of the diver being scarcely a quarter the size of those of the gull. Photographs of the two birds with the wings fully expanded, as in flight, are given at Plate clxxvi., Figs. 1 and 2, p. 1271. The wings are seen separately in Plate clxxi., Figs. 7 and 8, p. 1240.

I append measurements in confirmation.

Measurements of the Body and Wings of the Diver	
Length of body from tip of beak to tip of tail	18 ins.
Girth of body at widest part of chest	14 ,,
Length of beak, head, and neck	7 ,,
Length of body	$9\frac{1}{2}$,,
Length of tail	$1\frac{1}{2}$,,
Expanse of wings from tip to tip, measured across back	26 ,,
Length of wing from root to tip	$11\frac{1}{2}$,,
Breadth of wing where widest	$3\frac{1}{2}$,,
Breadth of primary feathers where widest	$2\frac{3}{4}$,,
Breadth of secondary feathers where widest	3 ,,
Width of secondaries nearest the body	$3\frac{1}{2}$,,

Measurements of the Body and Wings of the Sea-gull	
Length of body from tip of beak to tip of tail	$22\frac{1}{2}$ ins.
Girth of body at widest part of chest	$13\frac{1}{2}$,,
Length of beak, head, and neck	$8\frac{1}{4}$,,
Length of body	8 ,,
Length of tail	$6\frac{1}{4}$,,
Expanse of wings from tip to tip, measured across back	52 ,,
Length of wing from root to tip	25 ,,
Breadth of wing where widest	7 ,,
Breadth of primary feathers where widest	6 ,,
Breadth of secondary feathers where widest	8 ,,
Width of secondaries nearest the body	$7\frac{1}{2}$,,

SERIES OF EXPERIMENTS SHOWING EXCESS OF WING AREA IN THE FLY, DRAGON FLY, BUTTERFLY, HOUSE SPARROW, &c.

That no fixed relation exists between the area of the wings and the size and weight of the body, is evident on comparing the dimensions of the wings and bodies of the several orders of insects, bats, and birds. If such comparison be made, it will be found that the pinions in some instances diminish while the bodies increase, and the converse. No practical good can therefore accrue to aërostation from elaborate measurements of the wings and trunks of any flying thing; neither can any rule be laid down as to the extent of surface required for sustaining a given weight in the air. The wing area is, as a rule, considerably in excess of what is actually required for the purposes of flight. This is proved as follows. First by the fact that bats can carry their young without inconvenience, and birds elevate surprising quantities of fish, game, carrion, &c. I had in my possession at one time a tame barn-door owl which could lift a piece of meat a quarter of its own weight, after fasting four-and-twenty hours; and an eagle, as is well known, can carry a moderate-sized lamb with facility.

The excess of wing area is proved, secondly, by the fact that a large proportion of the wings of most volant animals may be removed without destroying the power of flight. I instituted a series of experiments on the wings of the fly, dragon-fly, butterfly, sparrow, &c., with a view to determining this point in 1867. The following are the results obtained:—

Blue-bottle Fly.—Experiment 1. Detached posterior or thin half of each wing in its long axis. Flight perfect.

Exp. 2. Detached posterior *two-thirds* of either wing in its long axis. Flight still perfect. I confess I was not prepared for this result.

Exp. 3. Detached one-third of anterior or thick margin of either pinion obliquely. Flight imperfect.

Exp. 4. Detached one-half of anterior or thick margin of either pinion obliquely. The power of flight completely destroyed. From Experiments 3 and 4 it would seem that the anterior margin of the wing, which contains the principal nervures, and which is the most rigid portion of the pinion, cannot be mutilated with impunity.

Exp. 5. Removed one-third from the extremity of either wing transversely, that is, in the direction of the short axis of the pinion. Flight perfect.

Exp. 6. Removed *one-half* from either wing transversely, as in Experiment 5. Flight very slightly (if at all) impaired.

Exp. 7. Divided either pinion in the direction of its long axis into three equal parts, the anterior nervures being contained in the anterior portion. Flight perfect.

Exp. 8. Notched two-thirds of either pinion obliquely from behind. Flight perfect.

Exp. 9. Notched anterior third of either pinion transversely. The power of flight destroyed. Here, as in Experiment 4, the mutilation of the anterior margin was followed by loss of function.

Exp. 10. Detached posterior two-thirds of right wing in its long axis, the left wing being untouched. Flight perfect. I expected that this experiment would result in loss of balancing-power; but this was not the case.

Exp. 11. Detached half of right wing transversely, the left one being normal. The insect flew irregularly and came to the ground about a yard from where I stood. I seized it and detached the corresponding half of the left wing, after which it flew away, as in Experiment 6.

Dragon-Fly.—Exp. 12. In the dragon-fly either the first or second pair of wings may be removed without destroying the power of flight. The insect generally flies most steadily when the posterior pair of wings are detached, as it can balance better; but in either case flight is perfect, and in no degree laboured.

Exp. 13. Removed one-third from the posterior margin of the first and second pairs of wings. Flight in nowise impaired.

If more than a third of each wing be cut away from the posterior or thin margin, the insect can still fly, but with effort.

Experiment 13 shows that the posterior or thin, flexible margins of the wings may be dispensed with in flight. They are more especially engaged in propelling. Compare with Experiments 1 and 2.

Exp. 14. The extremities or tips of the first and second pair of wings may be detached to the extent of one-third, without diminishing the power of flight. Compare with Experiments 5 and 6.

If the mutilation be carried further, flight is laboured, and in some cases destroyed.

Exp. 15. When the front edges of the first and second pairs of wings are notched or when they are removed, flight is completely destroyed. Compare with Experiments 3, 4, and 9.

This shows that a certain degree of stiffness is required for the front edges of the wings, the front edges indirectly supporting the back edges. It is, moreover, on the front edges of the wings that the pressure, more especially, falls in flight, and by these edges the major portions of the wings are attached to the body. The principal movements of the wings are communicated to these edges.

Butterfly.—Exp. 16. Removed posterior halves of the first pair of wings of a white butterfly. Flight perfect.

Exp. 17. Removed posterior halves of first and second pairs of wings. Flight not strong but still perfect. If additional portions of the posterior wings were removed, the insect could still fly, but with great effort, and came to the ground at no great distance.

Exp. 18. When the tips (outer sixth) of the first and second pairs of wings were cut away, flight was in nowise impaired. When more was detached the insect could not fly.

Exp. 19. Removed the posterior wings of a brown butterfly. Flight unimpaired.

Exp. 20. Removed in addition a small portion (one-sixth) from the tips of the anterior wings. Flight still perfect, as the insect flew upwards of ten yards.

Exp. 21. Removed in addition a portion (one-eighth) of the posterior margins of anterior wings. The insect flew imperfectly, and came to the ground about a yard from the point where it commenced its flight.

House Sparrow.—The sparrow is a heavy small-winged bird, requiring, one would imagine, all its wing area. This, however, is not the case, as the annexed experiments show.

Exp. 22. Detached the half of the secondary feathers of either pinion in the direction of the long axis of the wing, the primaries being left intact. Flight as perfect as before the mutilation took place. In this experiment, one wing was operated upon before the other, in order to test the balancing-power. The bird flew perfectly, either with one or with both wings cut.

Exp. 23. Detached the half of the secondary feathers and a fourth of the primary ones of either pinion in the long axis of the wing. Flight in nowise impaired. The bird, in this instance, flew upwards of thirty yards, and, having risen a considerable height, dropped into a neighbouring tree.

Exp. 24. Detached nearly the half of the primary feathers in the long axis of either pinion, the secondaries being left intact. When one wing only was operated upon, flight was perfect; when both were tampered with, it was still perfect, but slightly laboured.

Exp. 25. Detached rather more than a third of both primary and secondary feathers of either pinion in the long axis of the wing. In this case the bird flew with evident exertion, but was able, notwithstanding, to attain a very considerable altitude.

From experiments 1, 2, 7, 8, 10, 13, 16, 22, 23, 24, and 25, it would appear that great liberties may be taken with the posterior or thin margin of the wing, and the dimensions of the wing in this direction materially reduced, without destroying, or even vitiating in a marked degree, the powers of flight. This is no doubt owing to the fact

indicated by Sir George Cayley, and fully explained by Mr. Wenham, that in all wings, particularly long narrow ones, the elevating power is transferred to the anterior or front margin.

Exp. 26. Removed alternate primary and secondary feathers from either wing, beginning with the first primary. The bird flew upwards of fifty yards with very slight effort, rose above an adjoining fence, and wheeled over it a second time to settle on a tree in the vicinity. When one wing only was operated upon, it flew irregularly and in a lopsided manner.

Exp. 27. Removed alternate primary and secondary feathers from either wing, beginning with the *second primary.* Flight, from all I could determine, perfect. When one wing only was cut, flight was irregular or lopsided, as in Experiment 26.

From Experiments 26 and 27, as well as Experiments 7 and 8, it would seem that the wing does not of necessity require to present an unbroken or continuous surface to the air, such as is witnessed in the pinion of the bat, and that the feathers, when present, may be separated from each other without destroying the utility of the pinion. In the raven and many other birds the extremities of the first four or five primaries divaricate in a marked manner. A similar condition is met with in the *Alucita hexadactyla*, where the delicate feathery-looking processes composing the wing are widely removed from each other. The wing, however, *ceteris paribus*, is strongest when the feathers are not separated from each other, and when they *overlap*, as then they are arranged so as mutually to support each other.

Exp. 28. Removed half of the primary feathers from either wing transversely, that is, in the direction of the short axis of the wing. Flight very slightly, if at all, impaired when only one wing was operated upon. When both were cut, the bird flew heavily, and came to the ground at no very great distance. This mutilation was not followed by the same result in Experiments 6 and 11. On the whole, I am inclined to believe that the area of the wing can be curtailed with least injury in the direction of its long axis, by removing successive portions from its posterior margin.

Exp. 29. The carpal or wrist-joint of either pinion rendered immobile by lashing the wings to slender reeds, the elbow-joints being left free. The bird, on leaving the hand, fluttered its wings vigorously, but after a brief flight came heavily to the ground, thus showing that a certain degree of twisting and folding, or flexing of the wings, is necessary to the flight of the bird, and that, however the superficies and shape of the pinions may be altered, the movements thereof must not be interfered with. I tied up the wings of a pigeon in the same manner, with a precisely similar result.

The birds operated upon were, I may observe, caught in a net, and the experiments made within a few minutes from the time of capture.

Some of my readers will probably infer from the foregoing, that the figure-of-8 curves formed along the anterior and posterior margins of the pinions are not necessary to flight, since the tips and posterior margins of the wings may be removed without destroying it. To such I reply, that the wings are flexible, elastic, and composed of a congeries of curved surfaces, and that so long as a portion of them remains, they form, or tend to form, figure-of-8 curves in every direction.

Captain F. W. Hutton, in a paper "On the Flight of Birds" (*Ibis*, April 1872), refers to some of the experiments detailed above, and endeavours to frame a theory of flight, which differs in some respects from mine. His remarks are singularly inappropriate, and illustrate in a forcible manner the old adage, "A little knowledge is a dangerous thing." If Captain Hutton had taken the trouble to look into my memoir "On the Physiology of Wings," communicated to the Royal Society of Edinburgh on the 2nd of August 1870,[1] fifteen months before his own paper was written, there is reason to believe he would have arrived at very different conclusions. Assuredly he would not have ventured to make the rash statements he did make, the more especially as he attempts to controvert my views, which are based upon anatomical research and experiment, without making any dissections or experiments of his own.

§ 383. The Wing Area decreases as the Size and Weight of the Volant Animal increases.

While, as explained in the last section, no definite relation exists between the weight of a flying animal and the size of its flying surfaces, there being, as stated, heavy-bodied and small-winged insects, bats, and birds, and the converse ; and while, as I have shown by experiment, flight is possible within a wide range, the wings being, as a rule, in excess of what are required for the purposes of flight ; still it appears, from the researches of M. de Lucy, that there is a general law, to the effect that the larger the volant animal the smaller by comparison are its flying

[1] "On the Physiology of Wings, being an Analysis of the Movements by which Flight is produced in the Insect, Bat, and Bird." (*Trans. Roy. Soc. of Edinburgh*, vol. xxvi.)

surfaces. The existence of such a law is very encouraging as far as artificial flight is concerned, for it shows that the flying surfaces of a large, heavy, powerful flying machine will be comparatively small, and consequently comparatively compact and strong. This is a point of very considerable importance, as the object desiderated in a flying machine is elevating capacity.

M. de Lucy has tabulated his results, which I subjoin :[1]—

INSECTS.				BIRDS.			
NAMES.	Referred to the Kilogramme =2 lbs. 8 oz. 3 dwt. 2 gr. Avoird. =2 lbs. 3 oz. 4·428 dr.			NAMES.	Referred to the Kilogramme.		
	sq. yds.	ft.	in.		sq. yds.	ft.	in.
Gnat	11	8	92	Swallow	1	1	104½
Dragon-fly (small)	7	2	56	Sparrow	0	5	142½
Coccinella (lady-bird)	5	13	87	Turtle-dove	0	4	100½
Dragon-fly (common)	5	2	89	Pigeon	0	2	113
Tipula, or daddy-long-legs	3	5	11	Stork	0	2	20
Bee	1	2	74½	Vulture	0	1	116
Meat-fly	1	3	54½	Crane of Australia	0	0	139
Drone (blue)	1	2	20				
Cockchafer	1	2	50				
Lucanus cervus { Stag-beetle (female)	1	1	39½				
Lucanus cervus { Stag-beetle (male)	0	8	33				
Rhinoceros-beetle	0	6	122½				

"It is easy, by the aid of this table, to follow the order, always decreasing, of the surfaces, in proportion as the winged animal increases in size and weight. Thus, in comparing the insects with one another, we find that the gnat, which weighs 460 times less than the stag-beetle, has fourteen times more of surface. The lady-bird weighs 150 times less than the stag-beetle, and possesses five times more of surface. It is the same with the birds. The sparrow weighs about ten times less than the pigeon, and has twice as much surface. The pigeon weighs about eight times less than the stork, and has twice as much surface. The sparrow weighs 339 times less than the Australian crane, and possesses seven times more surface. If now we compare the insects and the birds, the gradation will become even much more striking. The gnat, for example, weighs 97,000 times less than the pigeon, and has forty times more surface ; it weighs 3,000,000 times less than the crane of Australia, and possesses 149 times more of surface than this latter, the weight of which is about 9 kilogrammes 500 grammes (25 lbs. 5. oz. 9 dwt. troy, 20 lbs. 15 oz. 2¼ dr. avoirdupois).

"The Australian crane is the heaviest bird that I have weighed. It is that which has the smallest amount of surface, for, referred to the kilogramme, it does not give us a surface of more than 899 square centimetres (139 square inches), that is to say about an eleventh part of a square metre. But every one knows that these grallatorial animals are excellent birds of flight. Of all travelling birds they undertake the longest and most remote journeys. They are, in addition, the eagle excepted, the birds which elevate themselves the highest, and the flight of which is the longest maintained."[2]

The several points discussed in the foregoing pages can be readily verified and established by a reference to natural wing structures and natural wing movements. I have gone into the subject somewhat exhaustively, realising very fully the important bearing which natural wings and natural wing movements have upon artificial flight in all its forms. I therefore propose to take up in succession, and very fully illustrate from original photographs, drawings, and dissections :—

1st. The wings and wing movements of insects.

2nd. The wings and wing movements of birds, and

3rd. The wings and wing movements of bats and of pterodactyls (extinct flying reptiles).

[1] "On the Flight of Birds, of Bats, and of Insects, in reference to the subject of Aërial Locomotion," by M. de Lucy, Paris.
[2] M. de Lucy, op. cit.

ALL WINGS CONSTRUCTED ON A COMMON PRINCIPLE, NAMELY, THAT OF THE HELIX OR SCREW

Before dealing with the several wings and wing movements in detail, it is important to point out that all wings are formed upon a common pattern and act upon a common principle. This is true even of some of the winged seeds, as, for example, those of the ash and plane trees.

I append two plates of drawings taken from nature for the present work illustrating the structure of the wing in the insect, bird, and bat. A careful study of the figures of these plates shows conclusively that all wings are triangular in shape ; the base of the triangle being directed towards the bodies of the volant animals. The figures also show that each wing is carefully graduated, and that it tapers off in two directions, namely, from the root in the direction of the tip, and from the anterior margin in the direction of the posterior margin. The root and anterior margin of the wing are always the strongest parts.

The wing is elastic throughout ; the tip and posterior margin yielding most when subjected to pressure. The elasticity and unequal yielding of the wing when it is made to vibrate in the air are of the utmost consequence in flight, as they necessitate the forward travel of the wing, and of the body to which the wing is attached during the down and up strokes. They also cushion the wing and help it over its dead points during its upward and downward reciprocating movements.

While all wings have the same general appearance, structure, and function, they vary slightly as regards number. Thus, in insects, there may be two wings, as in the blue-bottle fly ; two main and two subsidiary wings, as in the wasp and cicada ; four large wings, as in the dragon-fly and butterfly ; two large wings and two elytra or wing-cases, as in the locust, and the stag and other large beetles. The elytra or wing cases serve two purposes ; they protect the wings when their possessors are resting, and they act as aëroplanes and parachutes during active flight. In flight they are extended on either side of the body, and, as they make a slight upward angle with the horizon and are concave beneath, they act as true kites. The elytra do not beat the air as ordinary wings do.

When there are two large and two small subsidiary wings, as in the wasp and bee, the two wings on either side of the insect are generally united by hooks and act as one wing. When there are four wings, and coupling hooks are absent, as in the dragon-fly, the two wings on each side act simultaneously, but separately.

At times, as in the water-bugs, the gradation or tapering of the wings is effected by a modification or blending of what are practically elytra and wings ; the anterior part of each wing being hard, horny, and chitinous—the posterior part being membranous. The hard, horny part tapers off at the tip and posteriorly, and the wing, as a whole, affords an excellent example of a triangular, graduated, elastic wing.

In the *Alucita hexadactyla*, the two wings are broken up into long, thin, flat, ribbon-shaped winglets bordered with fine hairs, which effectually entangle the air in flight, especially during the down stroke. They present a broken surface like the feathers of the wing of the bird during flexion. In certain birds, the primary or rowing feathers are separated towards their free extremities in extension and during the down stroke. In such cases the tips of the rowing feathers act independently. In insects, bats, and pterodactyls, the rule is continuity of the wing membrane.

In the locust, the wings proper, when at rest, can be folded up like fans. In the large beetles, they are folded transversely, and neatly tucked up under the elytra or wing-cases.

With few exceptions the wings of insects are transparent. This is especially the case in the dragon-fly and cicada, which reveal the graduated, gossamer, filmy texture of the wing to perfection.

All the points referred to above are illustrated in Plates clxvi. and clxvii. which follow.

PLATE CLXVI

Plate clxvi. illustrates the important fact that all wings, whether those of insects, birds, or bats, are formed on a common pattern, and act on a common principle. Thus they are, without exception, triangular in shape, elastic, and carefully graduated ; being thickest at the root and along the anterior margin, and thinnest at the tip and along the posterior margin.

They elevate and propel at one and the same time ; the tips of the wings acting more especially as elevators, the posterior margins as propellers. Wings, in every instance, are convex above and concave below ; an arrangement which enables them largely to evade the superimposed air during the up stroke, and to seize the nether air during the down stroke. They are slightly twisted in the direction of their length ; a circumstance due to the anterior and posterior margins being arranged in different planes and forming double *f* or figure-of-8 curves. In

PLATE CLXVI.

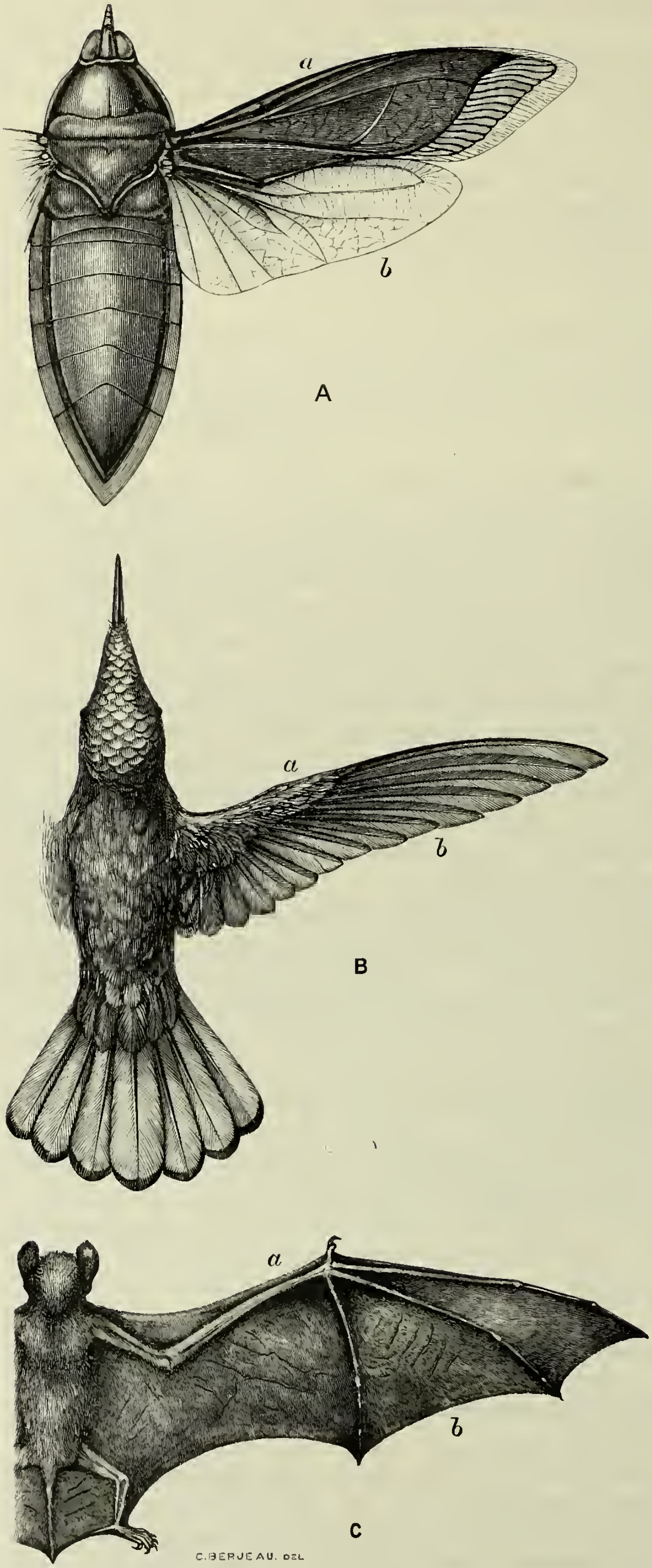


Fig. 1.

Fig. 2.

PLATE CLXVI (*continued*)

brief, all wings are screws structurally and functionally. (The figures in this plate are drawn from nature by C. Berjeau.)

FIG. 1.—A. The water-bug (*Belostoma*). Shows triangular, beautifully graduated, elastic, concavo-convex wing. *a*, Semi-rigid anterior margin tapering from the root to the tip of the wing ; *b*, thin, filmy, elastic, posterior margin of wing. The tip and posterior margin of the wing yield more than the root and anterior margin when the wing is made to vibrate in the air. The tip and posterior margin of the wing are the most efficient and active portions in flight.

B. The humming-bird. Displays a most dainty, exquisitely formed concavo-convex wing composed of bones, muscles, and feathers ; the latter radiating in an outward and backward direction. The feathers which take part in flight are divided into primary or rowing feathers (tip of wing), secondaries (middle portion of wing), and tertiaries (root of wing). The wing resembles in all respects that of the insect, with this difference, that the primary, secondary, and tertiary feathers open up and separate during flexion and the up stroke, and close during extension and the down stroke. The wing of the insect, and also that of the bat, presents a continuous unbroken surface during both the up and down strokes. *a*, Semi-rigid anterior margin tapering from root to tip of wing; *b*, posterior thin, elastic, yielding margin of wing formed by the free ends of the primary, secondary, and tertiary feathers.

C. The bat. In the bat, the peculiarities of the wing of the insect and bird are repeated. Thus, the wing is triangular in shape, concavo-convex, and elastic throughout. It tapers from the root towards the tip, and from the anterior towards the posterior margin. It is thickest, strongest, and most rigid at the root and along the anterior margin (*a*), and thinnest, weakest, and most elastic along the posterior margin (*b*). It presents a continuous membrane to the air during both the up and down strokes, as in the insect ; it, however, partially closes or folds during the up stroke and fully expands during the down stroke as in the bird. The wing consists of muscles, bones, and a continuous elastic membrane which is supported by the bones of the arm, fore-arm, and hand, and by the bones of the thigh, leg, and tail. It is a most elegantly constructed, serviceable wing, the bats being splendid flyers.

FIG. 2.—A. The stag beetle (*Macrodontia cervicornis*). This insect provides typical wings, and, in addition, elytra or wing-cases. The wing, like those already described, tapers, and is thickest at the root and along the anterior margin (*a*), and thinnest at the tip and along the posterior margin (*b*). The elytron or wing-case (*c*) is concavo-convex, and during flight is extended and directed forwards so as to be well out of the way of the wing when it is made to vibrate. When the insect is reposing the elytron occupies a position parallel with the body, one-half of the dorsal surface of which it covers—the corresponding wing being folded and tucked up beneath it. The elytron is composed of a light, tough, chitinous material, and acts as a parachute during flight—a function which it is well fitted to discharge, its under surface being deeply concave.

B. The swallow-tail butterfly (*Papilio machaon*). This is one of the swiftest of the butterflies. It has four wings : the anterior pair being triangular, elongated, and particularly well formed for elevating purposes, the posterior pair being equally well adapted for propelling purposes. The wings, as in other cases, are strongest at the root and along the anterior margin (*a*) and weakest at the tip and along the posterior margin (*b* and *d*). They are concavo-convex and elastic. The nervures or supports of the wing radiate outwards and backwards as in the wings of the bird and bat. The wings display all the peculiarities of ordinary wings both as regards structure and movement.

C. The goliath beetle. This insect possesses a very perfect wing, both as regards shape and structure. It is triangular in form, concavo-convex, beautifully graduated, and elastic throughout. It displays to perfection the nervures or supports of the wing ; these radiating in an outward and backward direction, as in the primary, secondary, and tertiary feathers of the wing of the bird. The nervures are most numerous and strongest at the root and along the anterior margin of the wing (*a*), and least numerous and feeble at the tip and along the posterior margin (*b*). The wing folds upon itself at *a*, when the insect is reposing, in which case the wing is arranged on the back and covered by its elytron (*c*). The elytra, in all the beetles, act as aëroplanes and parachutes during flight—their chief function being the protection of the wings when the animals are moving about on the ground or resting.

PLATE CLXVII

Plate clxvii.—The figures of this plate are accurate delineations of several types of insect wings drawn from nature for the present work by C. Berjeau. They are structurally identical with the wings figured in Plate clxvi., those of the *Alucita hexadactyla*, which are anomalous, excepted.

FIG. 1.—A. The dragon-fly (*Petalura gigantea*). The wings in this case are four in number—two anterior and two posterior, the posterior wings being slightly larger than the anterior ones. They are, in some respects, the most beautiful wings known. They are transparent and filmy, and reveal the most exquisite reticulations and tracery. The nervures or supports of the wings flow in graceful curved lines in an outward and backward direction, and, as the substance of the wings is mapped out into innumerable minute squares and pentagons, the general effect is that of the most delicate filigree work or the finest of lace. The nervures are thickest at the roots and along the anterior margins of the wings, and thinnest and fewest along the posterior margins. The wings are characterised by great length and narrowness, a circumstance which ensures great rapidity of flight. The dragon-fly is by far the swiftest of all the insects ; indeed it lives by hawking other flies. It is a perfect master in the art of flight, and its graceful evolutions in the air transcend those of every other flying thing. It is doubtful whether it can be captured when careering about in the open. The little hobby falcon of Bulgaria is said to be equal to this feat. The swallow is certainly no match for it, as I myself have been able to verify. Its flight closely resembles that of the swift, which is also remarkable for its great length and sweep of wing. The inconceivable suddenness with which the dragon-fly swerves to right or left and changes and checks its course makes it next to impossible for a bird heavier than it is to seize it. It literally plays with all other flying things. I know of no more wonderful sight than is afforded by a gaudily coloured dragon-fly hunting quietly in a glade with a smooth-flowing stream, its gorgeous pigmentation flashing ever and anon like fire. Its steady, rapid, onward flight, its graceful wheeling in every direction, its upward and downward movements and absolute control of the situation furnish an idyll for the much desired flying machine of the future. To see it hunted in turn by a swallow, swift, or other quick flying bird is the most exciting of all racing events. All other feats of wingmanship pale before that of the dragon-fly. I have seen an eagle hunting grouse, and a kestrel swooping down on small birds, but the sport is tame when compared with that in which the dragon-fly figures. The movements of the dragon-fly

PLATE CLXVII

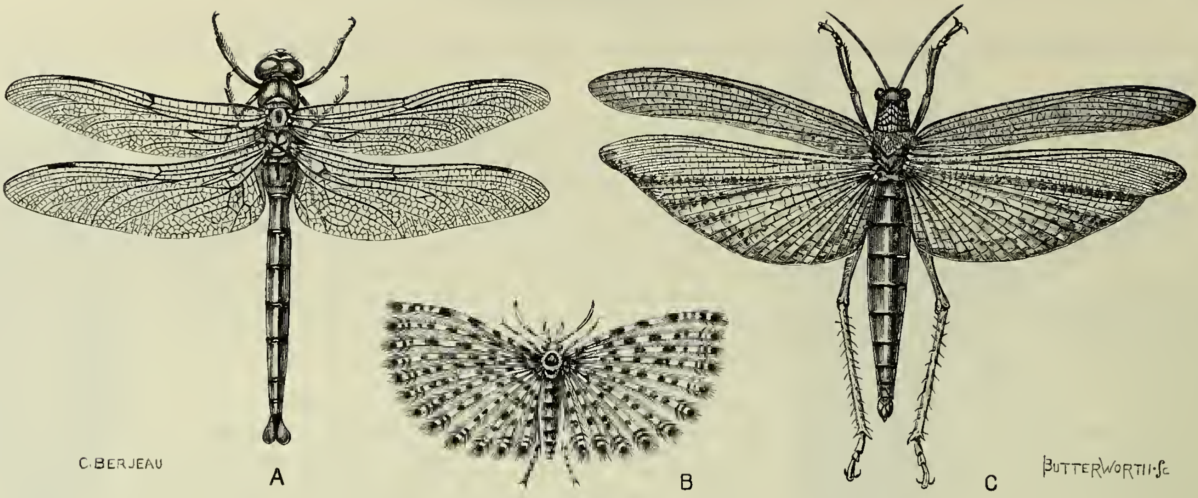


FIG. 1.

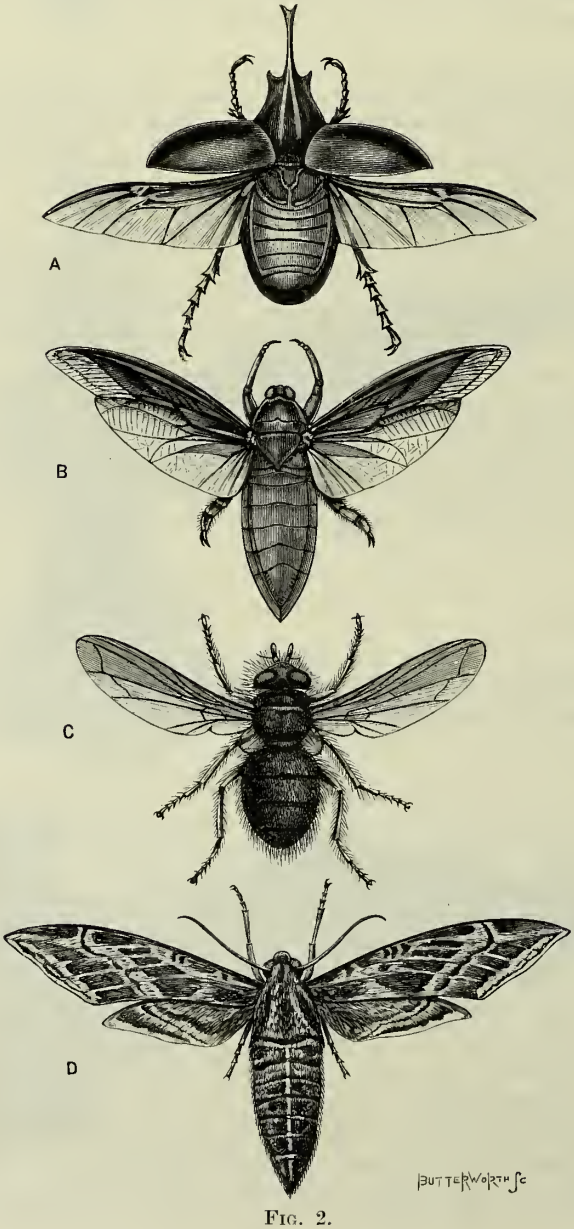


FIG. 2.

FIG. 2.

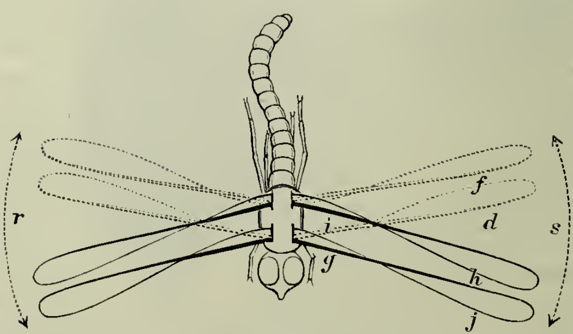


FIG. 3.

PLATE CLXVII (*continued*)

are so marvellously swift and smooth, and so thoroughly under control, that it is impossible to conceive of anything finer in the way of flight.

B. *Alucita hexadactyla.* The wings of this insect are more or less anomalous. They are triangular in shape and graduated as other wings are. They, however, differ in this, that they are split up into numerous thin, flat, narrow winglets, each of which is edged with a plentiful supply of delicate hairs, which are directed downwards and outwards from the centre of the winglet. The winglet with its fringe of hairs on each side is conical on section, the apex of the cone being directed upwards. This arrangement ensures that the winglets and their marginal hairs shall close up and entangle the air during the down strokes, and open up and permit it to escape during the up strokes. A fretted, partially broken surface is one of the best possible for entangling and seizing the air. The winglets act together, or simultaneously, during both the down and up strokes. In not a few birds, such as the vulture, eagle, heron, gannet, crow, pheasant, &c., in full extension and the down stroke, the primary or rowing feathers of the wing separate slightly at their free extremities. In all birds, the primary, secondary, and tertiary feathers separate, open up, and are thrown out of gearing during flexion and the up stroke. The arrangement of the winglets in the *Alucita hexadactyla*, although anomalous, is not wholly opposed to the arrangement of the feathers engaged in flight in birds.

C. The locust. This well-known and much-dreaded insect is provided with two large posterior wings and two anterior pseudo-wings or elytra. Both are transparent and gauzy-looking, as in the dragon-fly. The posterior wings are triangular in shape, and their nervures or supports radiate outwards and backwards. They can be folded up like fans. They are feeble structures—the locust being by no means a powerful flier. The pseudo-wings or elytra are long, narrow structures which correspond with the anterior portions of the posterior wings. When the locust is reposing and the posterior wings are folded up they cover and protect them. When the locust is flying they stand out at right angles to the body and act as aëroplanes or parachutes. I have frequently pursued flying locusts on the Riviera and marked their manner of flight. They fly comparatively slowly, and their movements are laboured and heavy. They make little progress unless when favoured by a stiffish breeze. They are, of course, comparatively heavy insects, and their wings, as stated, are structurally weak and feeble.

Fig. 2.—A. Beetle (*Augusoma centaurus*). This insect presents an example of a heavy body and small wings with elytra or wing-covers. The wings are triangular in shape and transparent. Their nervures or wing supports are directed outwards and backwards, and are strongest at the root and along the anterior margin of the wing and weakest at the tip and along the posterior margin. This arrangement causes the wing to twist and untwist in the direction of its length when it is made to vibrate—the thinnest portion of the wing yielding most freely to air pressure. The anterior margin of the wing forms, in a way, an axis round which the posterior margin plaits or twists. The elytra or wing-covers are deeply concave beneath, and form excellent parachutes or sustainers. The beetles, although heavy, are exceedingly good fliers, and their flight is generally accompanied by a musical drone which is very pleasant to listen to in the twilight or when the evening falls.

B. The cockroach (*Tetraclyta porosa*). The wings of this insect are composed of two hard, chitinous, graduated portions and two membranous portions which are hooked together to form two compound wings. Each compound wing is triangular in shape and beautifully graduated—the wing being thickest at the root and along the anterior margin, and thinnest at the tip and along the posterior margin. The cockroach, as was to be expected from its finely formed wings, is an admirable flier.

C. The bluebottle fly, considerably enlarged. This familar insect has long, narrow, transparent wings, and is a remarkably fine flier. Its flight is characterised by a booming musical note which is as characteristic of summer as the note of the cuckoo is of spring. Its wings are ample towards the tips, and their nervures or supports are arranged to give the necessary strength to these parts. The nervures radiate outwards and backwards, and are strongest at the roots and anterior margins of the wings and most feeble at the tips and posterior margins. The insect lends itself readily to experiment, and I find that if I remove the posterior margin of each wing by scissors I reduce the propulsive powers of the insect ; whereas if I remove the tips of the wings I reduce the elevating power. This is in some respects an important experiment, as it differentiates the functions performed by the several parts of the wings.

D. The sphinx moth. The wings of the moth are four in number, but they act together as two wings. The two wings taken together are long, narrow, and pointed, and are of a thick, soft texture. The moths are heavy insects, but the contour of the wings is such as to ensure them great powers of flight. The wings are non-transparent, but their nervures or wing supports can be traced. They are arranged as in other insects, and radiate in an outward and backward direction, being strongest at the root and anterior margin and weakest at the tip and posterior margin. Whenever long, narrow, pointed wings are found, speed and power of flight can be predicated with certainty, whether in the insect, bat, or bird.

E. The cicada (*C. septemdecim*). This is one of the best flying insects ; its body being compact and finely formed, and its wings, which are four in number, being ample, long, and somewhat narrow. The body and wings are carefully adapted to each other, and the spectator is impressed with the idea of fitness in the general arrangements. The wings are beautifully transparent, and the nervures or supports of the wings radiate in an outward and backward direction and are connected by transverse nervures which produce an open network. The nervures forming the anterior margins of the front wings are finely graduated, and taper from the root in the direction of the tips of the wings. The wings of the cicada may be regarded as typical wing structures. It is a curious circumstance that the winged seed of the plane tree greatly resembles them, both as regards general contour and venation (compare with Plate iv., Fig. 6).

F. Another variety of cicada. This insect greatly resembles that described under E ; the body being larger and the wings not quite so ample. The wings are four in number and deeply pigmented. The general shape and arrangement of the nervures of the wings is that met with in other insect wings, and need not be gone into. They are a repetition of those seen at E.

Fig. 3.—Diagram showing the movements made by the four wings of the dragon-fly during flight. The first thing to notice is that the posterior margins of the wings (*i*, *j*) twist or yaw round the anterior margins (*g*, *h*) as an axis, and so produce double-*f* or figure-of-8 curves. The extent or range of the up and down strokes is indicated at *r*, *s*.

It will be observed that at the beginning of the down stroke the anterior margin (*d*) of the wing is directed downwards and forwards ; the posterior margin (*f*) being directed upwards and backwards. At the end of the down stroke all this is reversed ; the anterior margin (*g*, *h*) of the wing is directed upwards and forwards ; the posterior margin (*i*, *j*) being directed downwards and backwards. This is due to the fact that during the down stroke the posterior margin twists or plaits round the anterior margin as an axis. In the diagram, it is the upper or dorsal surface of the wing which is seen at *f*, *d* (beginning of down stroke), whereas it is the under or ventral surface which is seen at *h*, *j* (end of down stroke). The wings of the dragon-fly pursue an oblique, more or less horizontal direction during the down stroke, but this can be varied so as to become more vertical at the will of the insect.

The winged seeds of the ash and plane trees remarkably resemble in structure the wings of the insect, bird, and bat.

Thus the seed of the plane tree is armed with two wings which are triangular in shape, and which are thickest at the root and along the anterior margin, and thinnest at the tip and along the posterior margin. They are also beautifully graduated in the directions indicated, and the venation of each wing wonderfully accords with the nervures of the wing of the insect, with the primary and secondary feathers of the wing of the bird, and with the fingers which afford support to the flying membrane of the wing of the bat.

The seed of the ash tree is remarkable in this, that it is twisted upon itself in the direction of its length, and forms a true screw, resembling the blade of an ordinary screw propeller as employed in steam navigation. Here again there is community of type with wings, which also form screws.

When the wings of insects, birds, and bats are viewed from above or from beneath, their anterior and posterior margins are apparently arranged in one plane. They are not so in reality. When they are viewed from before or behind, it is seen that the margins are arranged in different planes, and present double-*f* figure-of-8 curves; the wings, as a matter of fact, being slightly twisted in the direction of their length and forming screws. Even the primary or rowing feathers of the wing of the bird reveal the screw formation.

The wing of the bird during flexion and extension also displays the double-*f* figure-of-8 curves along its margins.

When the wings are made to vibrate, the double-*f* curves formed by their margins, as well as the planes of the wings, reverse. They thus form reciprocating screws—all wings being screws structurally and functionally. These several points are illustrated at Plate clxviii., which see.

PLATE CLXVIII

Plate clxviii.—The figures of this plate illustrate the spiral nature of the wing of the insect, bird, and bat; also the spiral nature of the primary or rowing feathers of the wing of the bird, and the spiral nature of certain winged seeds.

FIG. 1.—The wing of the beetle (*Goliathus micans*), as seen from above (upper figure) and from behind (lower figure). The lettering is the same in both figures. *d*, *e*, *f*, Anterior margin of wing; *c*, *a*, *b*, posterior margin of wing. The thin, highly flexible posterior margin twists or yaws round the semi-rigid anterior margin or axis when the wing is made to vibrate in the air. It displays double figure-of-8 curves when moving and also when at rest.

FIG. 2.—The wing of the bird (*Perdrix rubra*) shows the same points as in Fig. 1, the lettering being the same.

FIG. 3.—The wing of the bat shows the same points as in Figs. 1 and 2. The letters are the same in all three figures.

FIG. 4.—The first primary feather of the wing of the swan seen from above (upper Fig. A) and from before (lower Fig. B). Shows the same points as in Figs. 1, 2, and 3. The feather is beautifully curved in every direction, and forms a perfect mimic wing. It is convex above and concave below, and its margins display the double-*f* figure-of-8 curves to perfection. On transverse section (upper Fig. A) it also displays the *f* or double curve (*c*, *g*). It consists of the following parts: a midrib (*f*, *e*), which is concavo-convex and tapers from the root to the tip; an anterior margin (*c*, *d*), which curves slightly downwards at the proximal end of the feather and slightly upwards at the distal end; the posterior margin (*b*, *a*) curving in exactly opposite directions, namely, upwards at the proximal end and downwards at the distal end. The opposite curves made by the anterior and posterior margins of the feather are the homologues of similar curves made by the wing of the insect, bird, and bat, and bring into relief its screw structure. The opposite curves made by the wing of the bird in flexion and extension are seen at Fig. 8 of this plate. They are all double or *f* curves. At A of Fig. 8, the wing is flexed as seen during the up stroke; at C, it is extended as seen during extension and the down stroke.

FIG. 5.—The seed of the ash tree (*Fraxinus excelsior*). This seed is twisted in the direction of its length like the blade of the ordinary screw propeller employed in steamships. Its margins exhibit the double figure-of-8 curves in a marked manner, and show unmistakable evidence of community of structure (as far as outline is concerned) with the wing of the insect, bird, and bat, and with the chief wing feathers (primaries) of the bird. The seed of the ash is a winged seed, and the object of its screw configuration lies on the surface. It is intended to retard the fall of the seed, and so afford it an opportunity of being wafted by the wind to considerable distances where there is room to plant itself. It is most interesting to watch the shedding of the seeds of the ash tree in the autumn. If there be no breeze, they twirl round and round in a leisurely manner and fall not far from the root of the parent tree. If, however, a stiffish breeze springs up, they are whisked away, in some instances, to quite remarkable distances. The same is true of the seed of the plane tree, which is the most perfect example of a winged seed known.

Various other examples of winged seeds might be cited, prominent among which are the thistledown and goat's-beard—the latter forming a most elegant and perfect parachute.

FIG. 6.—The seed of the plane tree (*Acer pseudoplatanus*). This seed is remarkable in many ways: (*a*) as regards its weight; (*b*) as regards its shape; and (*c*) as regards its venation. It is a heavy double seed (*a*) united in the middle, and provided with two very perfect wings resembling in all respects the wings of insects, birds, and bats (compare with the upper figures of Figs. 1, 2, and 3 of this plate). The wings have all the characteristics of genuine wings; that is, they are triangular in shape, are elastic, and taper in two directions, namely, from the root in the direction of the tip, and from the anterior margin in the direction of the posterior margin. They have a thick, tapering, semi-rigid, anterior margin (*b*) and a thin, flexible, posterior margin (*c*), and the venation or wing supports curve outwards and backwards as in all the wings described. It would be difficult to produce a more perfect example of design and type in nature than is afforded by this winged seed. It shows that types are not confined to any one division of the organic kingdom, and that the First Cause employs the same or similar means to produce like results.

The winged seed of the plane tree twirls about in its fall as does the ash seed, and it is only when winds are blowing that it is carried to any considerable distance.

PLATE CLXVIII

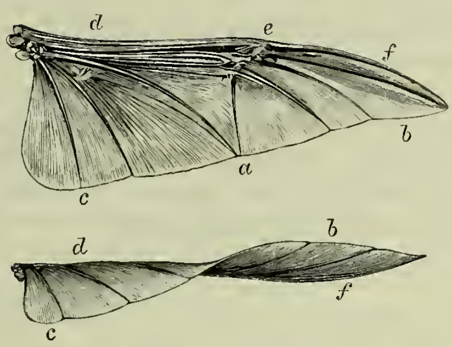


Fig. 1.

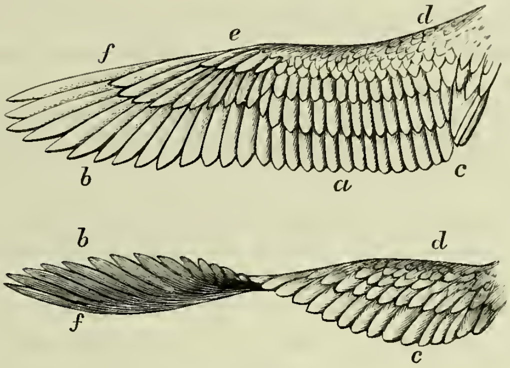


Fig. 2.

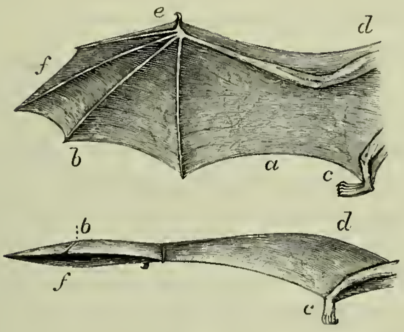


Fig. 3.

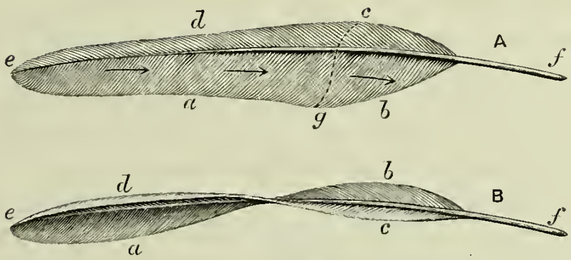


Fig. 4.

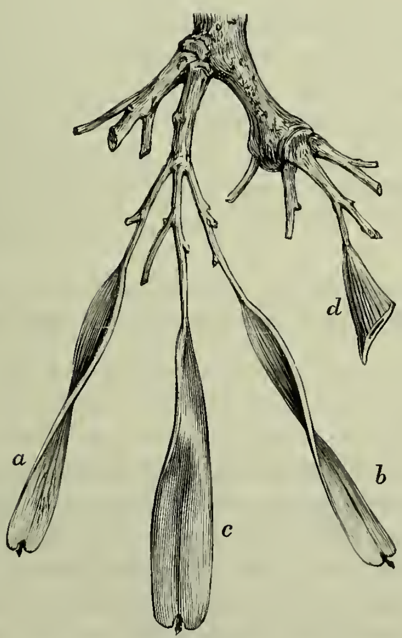


Fig. 5.

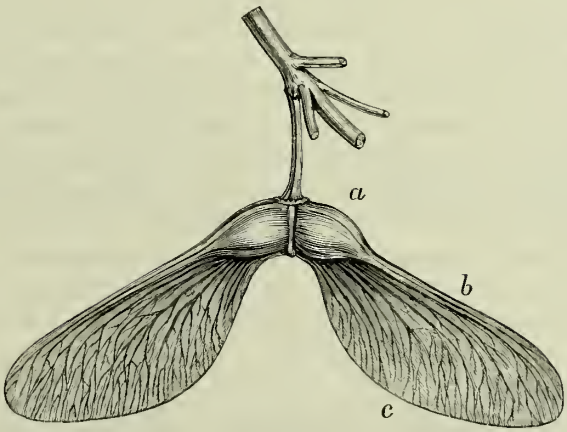


Fig. 6.

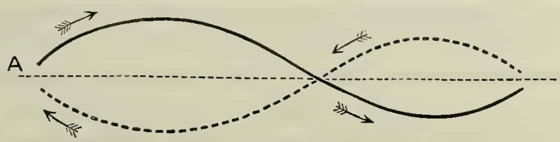


Fig. 7.

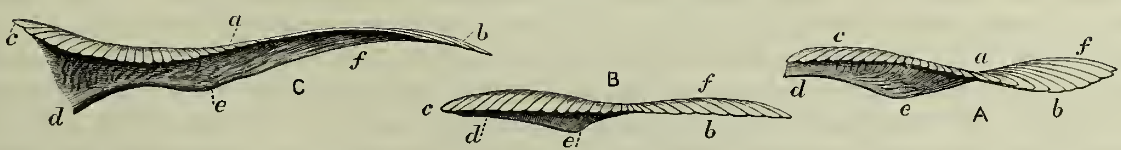


Fig. 8.

PLATE CLXVIII (*continued*)

Fig. 7.—Shows double-*f* figure-of-8 curves made by the margins of the wing of the bird during flexion and extension.
A. The line which intersects the curves during the movements in question. The solid line and darts indicate the double-*f* curves made by the wing in extension ; the interrupted line and darts that made during flexion.

Fig. 8.—Represents the wing of the bird in the flexed (A), semi-flexed (B), and extended (C) condition. The margins of the wings (*c*, *a*, *b*, *d*, *e*, *f*) are arranged in different planes, and make double-*f* figure-of-8 curves. In Fig. A (flexion) the posterior margin (*c*, *a*, *b*) makes a double-*f* curve, the convexity of which is directed upwards at *c* and do nwards at *b*. In Fig. B (extension) the curves are reversed ; the convexity of the curve at *c* being directed downwards, while the convexity of the curve at *b* is directed upwards. In Fig. B (semi-flexion and point of reversion) the curves on the posterior margin (*c*, *b*) of the wing are obliterated.
The wing in action is continually making, unmaking, and reversing its curves—a matter of the utmost importance, as by this means it is enabled to suddenly seize and suddenly let go the air on which it operates with such marvellous results.
The figures in this plate are by C. Berjeau and the Author.

THE WINGS OF INSECTS

§ 384. Anterior Wings (Elytra or Wing-cases)—their Shape and Uses.

The wings of insects may consist either of one or two pairs—the anterior pair, when two are present, being in some instances greatly modified and presenting a corneous condition. When so modified, they cover the posterior wings when the insect is reposing, and have from this circumstance been named elytra, from the Greek ἔλυτρον, a sheath. The elytra, or wing-cases, as they are sometimes called, are dense, rigid, and opaque in the beetles, solid in one part and membranaceous in another in the cockroaches, more or less membranous throughout in the grasshoppers, and completely membranous in the dragon-flies. The elytra are inclined at a certain angle when extended, and are indirectly connected with flight in the beetles, cockroaches, and grasshoppers. They are actively engaged in this function in the dragon-flies and butterflies. The elytra or anterior wings are frequently employed as *sustainers* or *gliders* in flight, the posterior or true wings acting more particularly as *elevators* and *propellers*. In such cases the elytra are twisted upon themselves after the manner of wings, the anterior margin of the wing-case towards its root, or where it joins the body, being bent *downwards* and *forwards*, while towards its extremity it is bent *upwards* and *backwards*. The anterior margin consequently presents two curves, the convexity of the curve nearest the body being directed downwards and forwards, the convexity of that furthest away from the body being, on the contrary, directed upwards and backwards. Similar but reverse curves are found on the posterior margin, so that the air which is caught by the concavity occurring *towards the extremity* of the wing-case anteriorly is prevented from escaping *towards the root* of the wing-case in a forward direction by the elytra in this situation, as has been explained, being bent downwards and forwards. It is therefore compelled to pursue a spiral, oblique, and backward course along the under surface of the wing-case, until it arrives at the root of the wing-case posteriorly, where it is liberated.

The curves observed on the anterior and posterior margins of the wing-case are essentially the same as those met with in corresponding positions in the wing of the bird. In many insects both the anterior and posterior pairs of wings are membranous.

§ 385. The Posterior Wings—their Nervures, Form, Function, &c.

The wings of insects present different degrees of opacity, those of the moths and butterflies being non-transparent, those of the dragon-flies, bees, and common flies presenting a delicate, filmy, gossamer-like appearance. Both the anterior and posterior pairs of wings have this feature in common, and it is fundamental : they are composed of a duplicature of the integument or investing membrane, and are strengthened in various directions by a system of hollow, horny tubes, known to entomologists as the nervures. These nervures taper towards the extremity of the wing, and are strongest towards its root and anterior margin, where they supply the place of the arm in birds and bats. They are variously arranged. In the beetles they pursue a somewhat longitudinal course, and are jointed to admit of the wing being folded up transversely beneath the elytra.[1] In the locusts they diverge from a common centre after the manner of a fan, so that by their aid the wing is crushed up or expanded as required ; whilst in the dragon-fly, where no folding is requisite, they form an exquisitely reticulated structure. The neuræ, it may be remarked, are strongest in the beetles where the body is heavy and the wing small. They decrease in thickness as those conditions are reversed, and entirely disappear in the minute *Chalcis* and *Psilus*.[2] The function of the neuræ has not been ascertained ; but as they contain spiral vessels which apparently com-

[1] The wings of the May-fly are folded transversely and longitudinally as well, so that they are crumpled up into little squares.
[2] Kirby and Spence, vol. ii., 5th edition, p. 352.

municate with the tracheæ of the trunk, some have regarded them as being connected with the respiratory system, whilst others have looked upon them as the receptacles of a subtle fluid, which the insect can introduce and withdraw at pleasure to obtain the requisite degree of expansion and tension in the wing. Neither hypothesis is satisfactory, as respiration and flight can be performed in their absence. They appear to me, when present, rather to act as mechanical stays or stretchers, in virtue of their rigidity and elasticity alone—their arrangement being such that they admit of the wing being folded in various directions, if necessary, during flexion, and give it the requisite degree of firmness during extension. They are, therefore, in every respect analogous to the skeleton of the wing in the bat and bird. In those wings which, during the period of repose, are folded up beneath the elytra, the mere extension of the wing in the dead insect, where no injection of fluid can occur, causes the nervures to fall into position, and the membranous portions of the wings to unfurl or roll out precisely as in the living insect, and as happens in the bat and bird. This result is obtained by the arrangement of the neuræ at the axis or root of the wing, the anterior one occupying a higher position than that further back, as in the leaves of a fan. The spiral arrangement occurring at the axis extends also to the margins, so that wings which fold up or close, as well as those which do not, are twisted upon themselves, and present a certain degree of convexity in the one direction and concavity in the other—their free edges supplying those fine curves which act with such efficacy upon the air in obtaining the maximum of resistance and the minimum of displacement. As illustrative examples of the form of wing alluded to, that of the sphinx-moth, beetle, and house-fly may be cited; the pinions in those insects act as helices or twisted levers, and elevate weights much greater than the area of the wing would seem to warrant. The insects adverted to fly, as a rule, with great accuracy and speed, and frequently in a straight line. The twisting of the wing upon itself before and during its action, to which I have directed attention, occurs also in the wing of the bat and bird, and has not, so far as I am aware, been adverted to in any of the existing treatises on flight. It is occasioned in the bird and bat by the spiral configuration of the articular surfaces of the bones of the wing, and by the rotation of the bones of the arm, fore-arm, and hand upon their long axes. In the insect it is due to the conformation of the shoulder-joint, this being furnished with a system of check ligaments, and with horny prominences or stops, set, as nearly as may be, at right angles to each other, and fashioned so as to necessitate the wing acting in the manner specified. The view here promulgated is discussed at length further on, and is calculated, it appears to me, to throw additional light on the theory and practice of flight. The twisting is least marked in those insects and birds whose wings are large as compared with their bodies. The butterfly may be cited as an example. Here the wings are unusually ample and, as a consequence, unusually flattened. The flat form of wing is, however, not calculated to act with velocity and precision, or to impress the air favourably. In other words, it does not respond to the rotation which occurs in all wings during flexion and extension to the same extent as the more twisted form, and as a result it smites the air clumsily, a circumstance which, taken in conjunction with the small body of the insect, fully explains the faltering, irregular course described by the order.

§ 386. The Threefold Action of the Wing in Insects.

The wing in the insect, as has been stated, is more flattened than in the bird; and advantage is taken on some occasions of this circumstance, particularly in heavy-bodied, small-winged, quick-flying insects, to reverse the pinion completely during the down and up strokes—the wing, during its descent, having its anterior or thick margin inclined *upwards* and *forwards*, whereas, during its ascent, the anterior or thick margin is inclined *upwards* and *backwards*. The object of this arrangement is to increase the *elevating* power, while it does not necessarily impair the *propelling* power. This is effected in the following manner: The posterior margin of the wing is made to rotate, during the down-stroke, in a direction *from above downwards* and *from behind forwards*—the anterior margin travelling in an opposite direction and reciprocating. The wing may thus be said to attack the air by a screwing movement *from above.* During the up or return stroke, on the other hand, the posterior margin of the wing is made to rotate in a direction *from below upwards* and *from before backwards*, so that by a similar but reverse screwing motion, the pinion attacks the air *from beneath.* A figure-of-8, compressed laterally and placed obliquely with its long axis running from left to right of the spectator, represents the movements in question. The down and up strokes, as will be seen from this account, cross each other, the wing smiting the air during its descent, *from above,* as in the bird and bat, and during its ascent, *from below,* as in the flying-fish and boy's kite. The pinion thus acts as a helix or screw in a *more or less horizontal direction, from behind forwards and from before backwards;* but it has a third function. It likewise acts as a screw in a *nearly vertical direction from below upwards.* It is to the upward screwing, or third function, that the wing of the insect owes its great elevating power. The threefold action of the insect's wing is well seen in the humble-bee, bee, wasp, house-

fly, and crane-fly. The threefold action of the wing is more perceptible in the wing of the insect than in the bird and bat; and this is most probably due to the fact that the wing of the insect, with few exceptions, is *in one piece*, the maximum and minimum of surface being secured by a simple rotation of the pinion on its long axis; whereas in the bird and bat it is *in several pieces*, the pinion, in addition to being rotated on its long axis, having its area more or less *increased* in extension and *decreased* in flexion.

The wing rotates on its long axis in opposite directions during extension and flexion, that is, during its descent and ascent; and if the rotation be conducted sufficiently far, it acts as an *elevator* in both directions, *propulsion* being performed almost exclusively by the more vigorous play of the pinion during its descent.

The position of the wings during repose, as well as their condition, varies; the wings in one case being folded transversely and arranged on the back, as in the beetle: in another they are folded both longitudinally and transversely, as in the May-fly; whilst in a third they are crushed together like a fan, as in the locust. When not folded, they may be raised vertically above the body, or slightly lowered, or extended horizontally, or inclined downwards, as in the roof of a house.

The movements of the wings in insects, birds, and bats are essentially the same. It is otherwise with the structure of the wings, the wing of the insect being in some respects rudimentary as compared with that of the bird and bat. The pinion in either case is to be regarded as a living, delicately organised structure, whose parts and proportions are adjusted with mathematical accuracy to the strength of the animal and the rapidity of the vibrations necessary to raise its weight from the ground. The wing, as a rule, is more or less triangular in shape, the base of the triangle being directed towards the body, the sides anteriorly and posteriorly. It is also conical on section from within outwards and from before backwards, this shape converting the pinion into a delicately graduated instrument, balanced with the utmost nicety, to satisfy the requirements of the muscular system on the one hand and the resistance and resiliency of the air on the other. Those conditions are necessary to correct the unequal strain to which the different portions of the wing are exposed in action, as well as to prevent shock to the system. While all wings are graduated as explained, innumerable varieties occur as to their general contour, some being falcated or scythe-like, others oblong, others rounded or circular, some lanceolate, and some linear. Thus far a parallelism may be established between the wing of the insect, bird, and bat; but when we come to speak of the margins of the pinion, we find the wings of birds and bats present little variety, whereas those of insects may be crenated, dentated, ciliated, fimbriated, digitated, or caudated. Still greater differences occur as to surfaces, the wings of bats and birds presenting a uniform appearance, those of insects being hairy, naked, farinose, scaly, veined, reticulated, and striated, as happens.

§ 387. Flight essentially a Spiral, Gliding Movement.

The angle at which the wing acts most efficaciously as a propeller and elevator, as indicated by an examination of the pinion of the living insect, bird, and bat when fully extended and ready to give the effective stroke, is something like one of 30° with the horizon. It varies, however, as has been explained, according as the animal is ascending, descending, or progressing at a high speed—the angle being least when the speed is greatest. As the angle referred to could not be uniformly maintained without a rotatory motion which would wrench the wings from their fixings, the wing is made to rotate on its long axis to the extent of something less than a quarter of a turn in one direction during extension, and a corresponding amount in an opposite direction during flexion. Since the wing, in performing this movement, travels from the plane of least resistance till it makes the angle in question, and back again, at each vibration, a certain degree of power is dissipated in simply applying and withdrawing the wing surfaces. The movement, moreover, is not quite so uniform as it would be if complete rotation supervened. On this head, however, there is little ground for complaint, the wing being presented to and withdrawn from the air with such dexterity as to rob flight to a great extent of its inequalities, and convert it into a more or less perfect gliding movement. The down and up strokes, being essentially different and opposite movements, tend likewise to equalise each other. The gliding referred to is occasioned by the gradual extension and depression of the wing, during the down stroke, and its gradual flexion and elevation during the return or up stroke, the one movement, in fact, gliding into the other. The wing in action consequently describes a spiral course *from within outwards*, and *from above downwards*, during extension or the effective down stroke, and *from without inwards*, and *from below upwards*, during flexion or the back up stroke. The result of this is, that the wing is piercing the wind in two directions at nearly the same instant of time—the interval which is consumed in extending and flexing the pinion being devoted principally to applying it to and withdrawing it from the air; that which elapses during the down and up strokes to urging the animal upwards and forwards. That the wing rotates upon its long axis, as explained, may be readily ascertained by watching the movement in the larger

domestic fly. If the wing be viewed during its vibrations from above, it will be found that the blur, or impression produced on the eye by its action, is more or less concave (the under surface of the blur being convex). This is due to the fact that the wing is spiral in its nature, and because, during its action, it twists upon itself in such a manner as causes it to describe a double curve, the one curve being directed upwards, the other downwards. The double curve or wave-track referred to is particularly evident in the flight of birds, from the greater size of their wings.[1] It may not inaptly be compared to the blade of an ordinary screw propeller, as employed in navigation. The effect obtained, moreover, is in some respects analogous, since the great velocity with which the wing is driven converts the impression or blur into what is equivalent to a solid for the time being in the same way that the spokes of a wheel in violent motion, as is well understood, completely occupy the space contained within the rim or circumference of the wheel. The following differences are to be noted, and they are of importance, as they seem to prove very satisfactorily the immense superiority of the wing over every form of screw propeller yet constructed.

§ 388. Points wherein the Screw formed by the Wings differs from the Propellers in use in Steamships.

1. In the blade of the ordinary screw propeller the integral parts are rigid and unyielding, whereas in the blade of the screw formed by the wing, and in the twisted blur produced by its action, they are mobile and plastic. This is a curious and interesting point, the more especially as it does not seem to be either appreciated or understood. The mobility and plasticity of the wing are necessary, because the pinion is an *elevating* and *sustaining organ*, as well as a *propelling* one.

2. The vanes of the ordinary two-bladed screw propeller have, as a rule, a very limited area, this corresponding to their area of revolution. The wings, on the other hand, have a wide range, and during their elevation and depression rush through an extensive space, the slightest movement at the root or axis of the wing being followed by a gigantic up or down stroke at the other extremity. As a consequence, the wings always act upon successive and undisturbed strata of air. The advantage gained by this arrangement in a thin medium like the air, where the quantity to be compressed is necessarily great, is simply incalculable.

3. In the ordinary screw the blades follow each other in rapid succession, so that they travel over nearly the same space, and operate upon nearly the same particles, whether water or air, in nearly the same interval of time. The limited area at their disposal is consequently not utilised, the action of the two blades being confined, as it were, to the same plane, and the blades being made to precede or follow each other in such a manner as necessitates the work being virtually performed only by one of them. This is particularly the case when the motion of the screw is rapid and the mass propelled is in the act of being set in motion, that is before it has acquired momentum. In this instance a large percentage of the moving or driving power is inevitably consumed in slip, from the fact of the blades of the screw operating on nearly the same particles of matter. It is otherwise with the wings. Here the blades, and the blurs which the blades produce when moving, are widely separated —the one being situated on the right side of the body and corresponding to the right wing, the other on the left and corresponding to the left wing. The wings do not therefore follow each other and travel over the same space, or compress the same particles, at any stage of their progress. On the contrary, the right wing traverses and completely monopolises the right half or hemisphere of a circle, the left wing in like manner appropriating and converting to its own uses the left and remaining half. The range or sweep of the two wings, when urged to their extreme limits, corresponds as nearly as may be to one entire circle.[2] By thus separating the blades of the screw, as happens in the wings, a double result is produced ; since the blades always act upon independent columns of air, and in no instance overlap or double upon each other. The advantages possessed by this arrangement are particularly evident when the motion is rapid—the natural screws formed by the wings being most efficient when the artificial ones are least so. As there is practically no limit to the velocity with which the wings may be driven, and as increased velocity necessarily results in increased elevating, propelling, and sustaining power, we have here a striking example of the manner in which Nature triumphs over art even in her most ingenious, skilful, and successful creations.

There is yet another advantage which ought not to be overlooked. The same power which propels a screw composed of two blades will suffice, or very nearly suffice, for driving the detached, widely separated blades of the screw formed by the wings.

[1] The late Duke of Argyll was of opinion that the curvature of the wing in birds is owing to the elasticity and bending *upwards* of the tips of primary, secondary, and tertiary feathers during the down stroke. It, however, also occurs in the wings of insects and bats, which are devoid of feathers ; so that I am inclined to refer it, as stated, to the conformation of the wing and to its peculiar mode of action.

[2] Of this circle, the thorax may be regarded as forming the centre, the abdomen, which is always heavier than the head, tilting the body slightly in an upward direction. This tilting of the trunk favours flight by causing the body to act after the manner of a kite.

4. The vanes or blades of the screw, as commonly constructed, are fixed at a given angle, and consequently always strike at the same degree of obliquity. Here, again, power is lost, the two vanes striking after each other in the same manner, in the same direction, and almost at precisely the same moment—no provision being made for increasing the angle and the propelling power, at one stage of the stroke, and reducing them at another, to diminish the amount of slip incidental to the arrangement. This result is obtained in marvellous perfection in the wings, and by a very simple contrivance, the angle which the pinions make with the horizon being gradually increased by the wings rotating on their long axes during the down or effective stroke, as it is usually termed, to increase the *elevating* and *propelling* power, and gradually decreased during the up or non-effective one to reduce the resistance occasioned by their ascent and backward movement, while it actually increases the *sustaining* area by placing the wing in a more horizontal position. It follows from this arrangement that every particle of air within the wide range of the wings is separately influenced by them, both during their ascent and descent —the elevating, propelling, and sustaining power being by this means increased to the utmost, while the slip or waftage is reduced to an infinitesimal and almost nominal amount. The effect aimed at is further secured by the undulatory or wave-like track described by the wing during the down and up strokes ; and it is a somewhat remarkable circumstance that the wing, when not actually engaged as a propeller and elevator, acts as a *sustainer* after the manner of a parachute. This it can readily do, alike from its form and the mode of its application, the double curve or spiral into which it is thrown in action enabling it to lay hold of the air with avidity, in whatever direction it is urged. I say " in whatever direction," because, even when it is being recovered or drawn off the wind during the back stroke, it is climbing a gradient which arches above the body to be elevated, and so prevents it from falling. It is difficult to conceive a more admirable, simple, or effective arrangement, or one which would more thoroughly economise power. Indeed, a study of the spiral configuration of the wing, and its spiral movements, involves some of the most profound problems in mathematics. The curves formed by the pinion as a pinion anatomically, and by the pinion in action or physiologically, are the most elegant and precise which it is possible to imagine : these run into each other, and merge and blend, to consummate the triple function of *elevating*, *propelling*, and *sustaining*. If further proof were necessary, it would be found in the fact that, during the down or effective stroke, the anterior and under extremity of the tip of the wing lays hold of the air with a biting or *concave surface* in a direction from above downwards, from behind forwards, and from without inwards, and forces it along a spiral groove on the under surface of the wing to the root of the same, where it causes it to escape by a *convex* one.

The under or ventral surface of the pinion is therefore engaged in elevating, propelling, and sustaining in a compound sense, one portion (the tip or outer part) *scaling* or *climbing* upwards and onwards, the root or inner portion aiding and abetting by *pushing* in a similar direction from beneath. In the return or back stroke, as has been explained, the curves formed by the under surface of the wing are reduced in such a manner as to decrease the amount of friction, while they increase, rather than diminish, the extent of sustaining area, the back or upper convex surface of the pinion being turned in the direction in which the wing travels during its ascent.

5. In the ordinary screw propeller of commerce, the bilge or backwater of the one blade is urged towards and interferes with the action of the opposite blade ; whereas in the wings, which are of necessity separated by the body which bears them, there is no such hindrance, and in fact no impediment whatever, each blade—that is, each wing—being free to utilise to the utmost the large subsidies of air on which it depends for support and progress.

6. The axis of revolution in the ordinary screw propeller corresponds to the plane of progression. The axes of the wings, on the other hand, are at right angles to it. The wings may therefore be said to combine, during their action, the grasp and steadiness of the paddle with the easy, subtle, gliding motion peculiar to the screw.

Other differences might be pointed out ; but the foregoing embrace the more fundamental and striking. Enough, moreover, has been said to show that it is to wing structures and wing movements the aëronaut must largely direct his attention, if he would learn " the way of an eagle in the air," and if he would rise upon the whirlwind in accordance with natural laws.

THE WING A TWISTED LEVER OR HELIX—ITS MODE OF ACTION IN THE INSECT, &c.

The twisting, screw-like action of the wing on its long axis during the up and down strokes, as well as the range of the pinion, are seen to advantage in the blow-fly. It can readily be made out by fixing the insect and holding it, with its head directed towards the spectator, against a dark background. The twisting in question is most marked in the posterior or thin margin of the wing, the anterior and thicker margin performing more the part of an axis. As a result of this arrangement, the anterior or thick margin cuts into the air quietly, and as it

were by stealth, the posterior one producing on all occasions a violent commotion, especially perceptible if a flame be exposed behind the insect. That the wing twists upon itself structurally, not only in the insect, but also in the bat and bird, any one may readily satisfy himself by a careful examination; and that it twists upon itself during its action, I have had the most convincing and repeated proofs. Indeed, it is matter for surprise that the spiral conformation of the pinion, and its spiral mode of action, should have eluded observation so long; and I shall be pardoned for dilating upon the subject when I state my conviction that it forms the fundamental and distinguishing feature in flight, and must be taken into account by all those who seek to solve this most involved and interesting problem by artificial means.

§ 389. Arrangement for Moving the Wings of Insects, &c.

In all insects, with the exception of the dragon-flies, the muscles which play the wings are confined within the barrel-shaped thorax to which the wings are articulated. They consist of a vertical and a transverse set—the transverse set, by their contraction, compressing the cylinder laterally, and causing its mesial portion *to ascend*, and the wings *to descend*, the vertical set, by their contraction, compressing the cylinder from above downwards, and causing the wings *to ascend*, in proportion as the vertical measurement of the thorax is reduced by lateral bulging. While the wings are ascending and descending, they are obliged to rotate on their long axes—the spiral configuration of the joints and the arrangement of the elastic and other structures which bind them to the body conferring on them the various degrees of obliquity which characterise the down and up strokes. As the two sets of muscles act alternately, as in the auricles and ventricles of the heart, the one set is being rested while the other is active; and it is just possible that in this and in the action of the elastic ligament which recovers or flexes the wing, we have an explanation not only of the prodigious power wielded by insects, but also of their endurance. In the libellulæ or dragon-flies, the muscles are inserted into the root of the wing, as in the bat and bird, the only difference being, that in the latter the muscles extend along the wing to its extremity. In all the wings which I have examined, whether in the insect, bat or bird, the wing is recovered, flexed, or drawn towards the body by the action of elastic ligaments, these structures, by their mere contraction, causing the wing, when fully extended and presenting its maximum of surface, to resume its position of rest and plane of least resistance. The principal effort required in flight would therefore seem to be made during extension, or when the effective stroke is being given. The elastic ligaments are variously formed, and the amount of contraction which they undergo is in all cases accurately adapted to the size and form of the wing and the rapidity with which it is worked—the contraction being greatest in the short-winged and heavy-bodied insects and birds, and least in the light-bodied and ample-winged ones, particularly in such as skim or glide. The mechanical action of the elastic ligaments, I need scarcely remark, ensures an additional period of repose to the wing at each stroke, and this is a point of some importance as showing that the lengthened and laborious flights of insects and birds are not without their stated intervals of rest.

§ 390. Speed attained by Insects.

Many instances might be quoted of the marvellous powers of flight residing in insects as a class. The male of the silkworm-moth (*Attacus paphia*) is stated to travel more than 100 miles a day; [1] and an anonymous writer in *Nicholson's Journal* [2] calculates that the common house-fly (*Musca domestica*), in ordinary flight, makes 600 strokes per second, and advances 25 feet; but that the rate of speed, if the insect be alarmed, may be increased six or sevenfold, so that under certain circumstances it can outstrip the fleetest racehorse. Leeuwenhoek relates a most exciting chase which he once beheld in a menagerie about 100 feet long between a swallow and a dragon-fly (*Mordella*). The insect flew with such incredible speed, and wheeled with such address, that the swallow, notwithstanding its utmost efforts, completely failed to overtake and capture it.[3]

§ 391. The Centre of Gravity in Insects—Articulation of the Wing to the Body of the Insect, &c.

The centre of gravity varies in insects according to the shape of the body, the length and shape of the limbs and antennæ, and the position, shape, and size of the pinions. It is corrected in some by curving the body, in others by bending or straightening the limbs and antennæ, but principally in all by the judicious play of the wings themselves.

[1] *Linn. Trans.*, vii., p. 40.

[2] Vol. iii., p. 36.

[3] "The hobby falcon, which abounds in Bulgaria during the summer months, hawks *large dragon-flies*, which it seizes with the foot and devours whilst in the air. It also kills swifts, larks, turtle-doves and bee-birds, although more rarely." ("Falconry in the British Isles," by Francis Henry Salvin and William Brodrick. London, 1855.)

To confer on the wing the multiplicity of movement which it requires, it is supplied with a double hinge or compound joint, which enables it not only to move in an upward, downward, forward, and backward direction, but also at various intermediate degrees of obliquity. An insect furnished with wings thus hinged may, as far as steadiness of body is concerned, be not inaptly compared to a compass set upon gimbals, where the universality of motion in one direction ensures comparative fixedness in another. The rapidity with which the wing oscillates is enormous. It varies, as has been explained, in proportion to the area of the wing and the body to be raised; but no method has as yet been devised for estimating the number of vibrations, from the fact that sound, in insects, is not always produced by the wings, so that the pitch of the note cannot be explained on the theory of vibrations as applied to acoustics.

I have endeavoured to explain that flight is secured in the insect, not because its body, as compared with the atmosphere, is comparatively light, but because its power, as compared with its size, is very great—this power enabling it to apply its wings to, and withdraw them from, the air with astonishing velocity *at various degrees of obliquity*, to obtain the maximum of resistance in a downward direction, and the minimum of displacement in an upward one; to convert them, in fact, into spiral inclined planes, with which to tread the air and rise upon it, as a kite upon the wind or a swimmer upon the water. I use the phrase "*various degrees of obliquity*" because, although the effective or down stroke is delivered at an angle of 30° or thereabouts, the wings act more or less perfectly as elevators and propellers from the moment they leave their position of rest, or plane of least resistance, until they make the angle referred to, and likewise during the up or back stroke, when the wings are being recovered. The power of the insect is consequently conserved and utilised to an astonishing degree.

In the years 1864, 1865, 1866, and 1867 I devoted a large amount of time and attention to the subject of natural and artificial flight in all their phases. I examined and dissected during these years a great number of insects', birds', and bats' wings. I also made numerous artificial fins, flippers, fish-tails, wings, and aërial screws. I, further, made extensive experiments with every available kind of natural and artificial wing, feeling convinced that the involved problem of flight could only be satisfactorily dealt with from the comparative anatomy and mechanical side, and by availing oneself of all the aids furnished by observation and by experiment with natural and artificial wings.

As the outcome of my investigations and experiments during the years in question, I delivered a lecture to the Royal Institution of Great Britain on the 22nd of March 1867, "On the Various Modes of Flight in Relation to Aëronautics." This lecture was illustrated by experiments with natural and artificial wings and aërial screws of various kinds, and an abstract of it was published in the *Proceedings* of the Institution of the above date. It was translated into French and other languages.

On the 6th and the 20th of June 1867, a Memoir by me "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom" was read to the Linnæan Society of London, communicated by Professor Huxley. This Memoir appeared in vol. xxvi. of the *Transactions of the Linnean Society*, with 4 plates (78 figures) and 19 woodcuts. In these two publications I described and delineated my original views of wing structures and wing movements, and, as I have never had reason to doubt their accuracy, it is important to give a short resumé of them in this place, not only in anticipation of what is to follow, but also to furnish an historical record of the progress of aëronautical science from the zoological standpoint.

At pages 99, 100, and 101 of my lecture published in the *Proceedings of the Royal Institution*, the spiral configuration of the wing in the insect is adverted to at length, and there described as a twisted lever or helix, which owes its peculiar elevating and propelling power in a great measure to its shape. Particular emphasis is also placed upon the partial rotation of the wing on its long axis during extension and flexion, and upon its screwing and unscrewing action during the down and up strokes, this being a *sine quâ non* in flight. In the pages alluded to the subjoined passages occur: "The wings of insects and birds are, as a rule, more or less triangular in shape, the base of the triangle being directed towards the body, the sides anteriorly and posteriorly. They are also conical on section from within outwards and from before backwards; this shape converting the pinion into a delicately graduated instrument, balanced with the utmost nicety to satisfy the requirements of the muscular system on the one hand, and the resistance and resiliency of the air on the other. . . . The neuræ or nervures in the insects' wing are arranged at the axis or root of the pinion, after the manner of a fan or a spiral stair; the anterior one occupying a higher position than that farther back, and so of the others. As this arrangement extends also to the margins, the wings are more or less twisted upon themselves, and present a certain degree of convexity on their superior or upper surface, and a corresponding concavity on their inferior or under surface; their free edges supplying those fine curves which act with such efficacy upon the air, in obtaining the maximum of resistance and the minimum of displacement; or, what is the same thing, the maximum of support with the minimum of slip. . . . All wings obtain their leverage by presenting oblique surfaces to the air, the

degree of obliquity gradually increasing in a direction from behind forwards and downwards during extension, when the sudden or effective stroke is being given, and gradually decreasing in an opposite direction during flexion, or when the wing is being more slowly recovered preparatory to making a second stroke. The effective stroke in insects (and this holds true also of birds) is therefore delivered downwards and forwards, and not, as the majority of writers believe, vertically, or even slightly backwards. . . .

"To confer on the wing the multiplicity of movement which it requires, it is supplied at its root with a double hinge or compound joint, which enables it to move not only in an upward, downward, forward, and backward direction, but also at various intermediate degrees of obliquity. . . .

"The wing of the bird, like that of the insect, is concavo-convex, and more or less twisted upon itself. The twisting is in a great measure owing to the manner in which the bones of the wing are twisted upon themselves, and the spiral nature of their articular surfaces, the long axes of the joints always intersecting each other at nearly right angles. As a result of this disposition of the articular surfaces, the wing may be shot out or extended, and retracted or flexed in nearly the same plane, the bones of the wing rotating in the direction of their length during either movement. This secondary action, or the revolving of the component bones upon their own axes, is of the greatest importance in the movements of the wing, as it communicates to the hand and forearm, and consequently to the primary and secondary feathers which they bear, the precise angles necessary for flight. It, in fact, insures that the wing, and the curtain or fringe of the wing, which the primary and secondary feathers form, shall be screwed into and down upon the wind in extension, and unscrewed or withdrawn from the wind during flexion. The wing of the bird may therefore be compared to a huge gimlet or auger, the axis of the gimlet representing the bones of the wing, the flanges or spiral thread of the gimlet the primary and secondary feathers."

The principal object of the Memoir is to establish an analogy between the walking surfaces of quadrupeds, the swimming surfaces of fishes, and the flying surfaces of insects, birds, and bats. These are all described and figured as twisted levers or screws in an anatomical sense, and as flexible reversing screws in a functional or physiological sense. As a consequence, the quadruped and biped are represented as walking, and the seal and fish as swimming, in figure-of-8 or looped curves. The wings of the insect, bird, and bat, are also described and figured as executing figure-of-8 movements when the animals are hovering before an object, or when their bodies are artificially fixed; the figure-of-8, as I explained, being opened out or unravelled when the animals are flying at a high horizontal speed to form a looped and then a waved track.

The following brief passages from my Memoir in the *Transactions of the Linnean Society* (vol. xxvi.) will serve to elucidate the peculiar figure-of-8 movements made by the wings in flight: "That the wing twists upon itself structurally, not only in the insect, but also in the bird and bat, any one may readily satisfy himself by a careful examination, and that it twists upon itself during its action I have had the most convincing and repeated proofs. The twisting in question is most marked in the posterior or thin margin of the wing, the anterior or thicker margin performing more the part of an axis. As a result of this arrangement, the anterior or thick margin cuts into the air quietly, and as it were by stealth, the posterior one producing on all occasions a violent commotion, especially perceptible if a flame be exposed behind the wing."

WHEN THE BODY OF THE VOLANT ANIMAL IS FIXED, AND ITS WINGS ARE MADE TO VIBRATE, THEY DESCRIBE FIGURE-OF-8 TRAJECTORIES IN THE AIR

"The twisting or rotating of the wing on its long axis is particularly observable during extension and flexion in the bat and bird, and likewise in the insect, especially the beetles, cockroaches, and others which fold their wings during repose. In these, in extreme flexion, the anterior or thick margin of the wing is directed downwards, and the posterior or thin one upwards. In the act of extension, however, the margins, in virtue of the wing rotating upon its long axis, reverse their positions, the anterior or thick margins describing a spiral course from below upwards, the posterior or thin margins describing a similar but opposite course from above downwards. These conditions, I need hardly observe, are reversed during flexion. The movements of the margins during flexion and extension may be represented with a considerable degree of accuracy by a figure-of-8 laid horizontally. . . . A figure-of-8, compressed laterally and placed obliquely with its long axis running from left to right of the spectator, represents the movement in question. The down and up strokes, as will be seen from this account, cross each other, the wing smiting the air during its descent from above, as in the bird and bat, and during its ascent from below, as in the flying-fish and boy's kite. The pinion thus acts as a helix or screw in a more or less horizontal direction from behind forwards, and from before backwards; but it has a third function—it likewise acts as a

screw in an early vertical direction from below upwards. . . . If the wing (of the larger domestic fly) be viewed during its vibrations from above, it will be found that the blur or impression produced on the eye by its action is more or less concave. This is due to the fact that the wing is spiral in its nature, and because during its action it twists upon itself in such a manner as to describe a double curve, the one curve being directed upwards, the other downwards. The double curve referred to is particularly evident in the flight of birds from the greater size of their wings. The wing, both when at rest and in motion, may not inaptly be compared to the blade of an ordinary screw propeller as employed in navigation. Thus the general outline of the wing corresponds closely with the outline of the propeller, and the track described by the wing in space is twisted upon itself propeller fashion. The great velocity with which the wing is driven converts the impression or blur into what is equivalent to a solid for the time being, in the same way that the spokes of a wheel in violent motion, as is well understood, completely occupy the space contained within the rim or circumference of the wheel. . . . From these remarks it will appear that not only the margins, but also the direction of the planes of the wing, are more or less completely reversed at each complete flexion and extension; and it is this reversing, or screwing and unscrewing, which enables the wing to lay hold of the air with such avidity during extension, and to disentangle itself with such facility during flexion—to present, in fact, a more or less concave, oblique, and strongly resisting surface the one instant, and a comparatively narrow, non-resisting, cutting edge the next. The figure-of-8 action of the wing explains how an insect or bird may fix itself in the air, the backward and forward reciprocating action of the pinion affording support, but no repulsion. In these instances, the backward and forward strokes are made to counterbalance each other."

WHEN THE BODY OF THE VOLANT ANIMAL IS ADVANCING, AND ITS WINGS ARE MADE TO VIBRATE, THEY DESCRIBE FIRST LOOPED AND THEN WAVED TRACKS IN SPACE

"Although the figure-of-8 represents with considerable fidelity the twisting of the wing upon its long axis during extension and flexion, when the insect is playing its wings before an object, or still better, when it is artificially fixed, it is otherwise when the down stroke is added, and the insect is fairly on the wing, and progressing rapidly. In this case the wing, in virtue of its being carried forwards by the body in motion, describes an undulating or spiral course."

§ 392. Mode of Investigation pursued by the Author.

I obtained my results by transfixing the abdomen of insects with a fine needle, and watching the wings vibrate against a dark background; by causing dragon-flies, butterflies, blow-flies, wasps, bees, beetles, &c., to fly in a large bell jar, one side of which was turned to the light, the other side being rendered opaque by dark pigment; by throwing young pigeons and birds from the hand into the air for the first time; by repeated observation of the flight of tame and wild birds; by stiffening, by tying up, and by removing portions of the wings of insects and birds; by an analysis of the movements of the travelling surfaces of quadrupeds, amphibia, and fishes; by the application of artificial fins, flippers, tails, and wings to the water and air; and by repeated dissections of all the parts directly and indirectly connected with flight.

§ 393. The Muscles and Joints of the Wing.

The muscles which propel the wing of the insect are, for the most part, confined to the thorax: in the bird and bat they occupy the thorax, but they also extend along the anterior margin of the wing itself.

The wing is united to the body in each case by what is practically a ball-and-socket joint which admits of movement in every direction—namely, upwards, downwards, forwards, backwards—and at every degree of obliquity. The body of the volant animal is in the position of a ship's compass set upon gimbals. It is equally balanced from every point, and is free to swim about in every direction. This arrangement produces an automatic or self-adjusting, balancing machinery, which secures absolute stability for the body of the flying creature whatever the position of the wings.

In the insect, the root of the wing is provided with springs, and a system of prominences, stops, or gags, which regulate the movements of the wing throughout its entire revolution. At no point in its course are the movements of the wing haphazard.

In the bird and bat, the wing is supplied with separate elevator and depressor muscles, with muscles and tendons which extend from the root to the tip of the wing, and with elastic structures which enable these animals to regulate the wing movements with the utmost nicety. The movements of the wing during the up and down strokes, and during flexion and extension, are thoroughly under control. Flight, in nature, is no mere mechanical problem. It is achieved, in every instance, by voluntary, carefully regulated, purposive movements. The muscles, joints, and elastic structures of the wing of the bird are fully described further on.

§ 394. Mechanical Theory of the Action of the Insect's Wing as stated by Chabrier.

In one instance only, according to Chabrier,[1] are the muscles in flight in insects inserted directly into the root of the wing. This solitary example is the dragon-fly. Chabrier regards the action of the insect's wing as purely mechanical. His argument may be stated in a few words. He observes, that whereas the muscles which propel the wings of the insect are, with one exception (the dragon-fly), confined to the interior of the thorax, therefore they exert no direct influence upon the wings. He further gives it as his opinion, that the wings are actuated by the muscles *only during the down stroke*, and that the up stroke is entirely due to the reaction of the air—in fact, that if the wings only be depressed rhythmically, the air will do the remainder of the work. Unfortunately for this theory there is no time to wait for the reaction of the air, the wings being driven with such velocity as necessitates their being partly elevated either by elastic ligaments or elevator muscles, in addition to the reaction of the air. Chabrier, as will be seen, delegates to the air the task of reversing the planes of the wing, and of conferring upon it *those peculiar curves* which, overlooked by him, I have endeavoured to show are indispensable in flight. In short, he confides to the air the delicate task of arranging the details of flight, those details constituting in reality the most difficult part of the problem.

§ 395. Objections to the Mechanical Theory of Wing Movements.

There are many facts which militate against Chabrier's mechanical theory of the movements of the insect's wing. I find, for example, that if the wing of the wasp, fly, humble-bee, or butterfly be depressed by a delicate rod, its posterior margin is made to curve downwards, and to make various angles with the horizon; the wing, the instant the rod is removed, being flexed and elevated by the action of elastic ligaments which obliterate the angles formed during the depression. This implies the existence of a muscular system for depressing the wing, and a fibro-elastic system for elevating it, similar to what is found in the bat and bird, to be described presently. It also proves that the wing is jointed to the body in such a manner that it cannot either descend or ascend without changing the direction of its planes (surfaces)—the air taking no part in the change of plane referred to.

I find, secondly, that insects have the power of vibrating either wing by itself in any part of a radius not exceeding a half circle, and that the wing may be played above the body or on a level with or beneath it, as circumstances demand. These facts argue a much more intimate relation between the muscular system and the wings than Chabrier is inclined to admit.

Thirdly. The wing in most insects is composed of two distinct portions at its root, those portions being endowed with independent movements, which enable the insect to incline the anterior or thick margin of the wing in one direction, and the posterior or thin margin in another—to twist, in fact, the wing upon its long axis. This twisting of the wing upon its long axis exerts upon the organ precisely the same influence which the extending and flexing of the pinion does upon the wing of the bird and bat. *It, in short, develops double or figure-of-8 curves along the anterior and posterior margins, and converts the wing into a screw capable of change of form.*

Fourthly. In the humble bee and other insects supplied with two pairs of wings geared to each other by hooklets, the posterior or thin margin of the first wing glides along the anterior or thick margin of the alula or second wing, which latter, acting as a long lever, has the power of adjusting the posterior or thin margin of the first wing.

Fifthly. In the wasp the first wing can be distinctly folded upon itself in the direction of its length, the alula or second wing folding upon the first wing previously folded, so that the area of the two wings is reduced to about one-third of what it was before the folding took place. When the wing is so folded it is very compact, and presents a well-defined cutting edge, which points in a backward direction. I am induced to believe that

[1] *Mémoires du Muséum d'Histoire Naturelle*, tome septième, Paris, 1821; *Essai sur le vol des Insectes*, par I. Chabrier, p. 297, Plates x., xi., and xii.

the wing is folded after this fashion in certain cases during the back or return stroke, although the action of the pinion is so rapid that I have hitherto failed to make it out.

Sixthly. Many insects, such as the ephemera, beetles, locusts, &c., have assuredly the power of more or less completely crumpling their wings, and of alternately increasing and diminishing the wing area during the down and up strokes. The wings of most insects, moreover, are during the up stroke thrown into rugæ, which are flattened or altogether disappear during the up stroke, and are opened out so as to increase their area during the down one. The butterfly affords an admirable example.

§ 396. Method of Demonstrating the Accuracy of the Figure-of-8 Movements made by all Wings.

The correctness of the figure-of-8 theory of flying may be readily established by a careful study of the rapidly vibrating wing of the wasp or of the common blow-fly.

If the body of the former be held, and the wing made to vibrate in front of a dark screen, it will be found that not only the tip but also the margins of the wing describe a figure-of-8 track in space.

It will further be observed that the planes (surfaces) of the wing are as a rule reversed during the down and up strokes; nay, more, that the angles of inclination made by the surfaces of the wing with the horizon vary at every stage of the wing's progress, this variation in the angles being accompanied by a variation in the curves occurring on the anterior and posterior margins, as already explained. As a consequence, the wing is moving in all its parts at the same time—a somewhat remarkable occurrence, and calculated, it appears to me, to excite the curiosity, if it does not rivet the attention, of physiologists. The wing of the insect is, with few exceptions, more flattened than that of the bat and bird; a circumstance which enables it, when it is made to vibrate in a more or less horizontal direction, and when its planes are reversed at the end of each stroke, to apply its under or ventral surface to the air when it is urged from behind forwards, and its upper or dorsal one when urged from before backwards.

The direction of the stroke varies slightly according to circumstances, but it will be quite proper to assume that the wing of the insect is made to vibrate in a more or less *horizontal direction*, and that of the bird and bat in a more or less *vertical direction*. By a slight alteration in the position of the body, or by a rotation of the wing in the direction of its length, the vertical direction of the stroke is converted into a horizontal direction, and *vice versâ*. The facility with which the direction of the stroke is changed is greatest in insects; it is not uncommon to see them elevate themselves by a figure-of-8, *horizontal*, screwing motion, and then, suddenly changing the horizontal screwing into a more *vertical* one, to dart rapidly forward in a curved line. The horizontal screwing movement is represented at Figs. 5 and 6, and the vertical screwing one at Fig. 7, of Plate clxx., p. 1236 of the present work. Whether the wing is made to vibrate vertically or horizontally, it, practically speaking, in *progressive flight*, strikes *downwards and forwards* during the down stroke, and *upwards and forwards* during the up stroke.

I now submit a careful analysis of the movements of the wing of the living insect, the result of personal observation and experiment, as recorded by original drawings made by me at various periods from 1867 to 1879 and subsequently.

The analysis is based chiefly on the movements of the wing of the common house-fly, the bluebottle-fly, the crane-fly, the bee, the humble-bee, the wasp, the dragon-fly, and the butterfly. It, however, embraces quite a large number of other insects to which it is not necessary to refer, as the principle of flight is the same in all.

On looking over some of my old notes "On Flight" dated 16th, 18th, and 20th of August 1879, I came upon original descriptions and delineations of the wing movements of the common house-fly and crane-fly which are so strongly confirmatory of what I have already said and have still to say regarding flight, that I cannot do better than transfer them to these pages. At the dates in question I gave three views of the movements of the wings of the house-fly, and four views of the movements of the wings of the crane-fly (see Plate clxix., p. 1234, Fig. 1, A, B, C; and Figs. 2, 3, 4, and 5).

In Fig. 1 (A, B, C) the house-fly is considerably enlarged, the better to show the wing movements.

These movements are best seen in the sunlight where an artificial dark background of some kind is employed. There is no difficulty in following them under such circumstances, especially if the observer has a trained eye, and is accustomed to note and analyse rapid animal movements.

§ 397. Flight of the Common House-fly.

I find I have depicted the house-fly as it flies upwards, as it poises and balances itself in mid-air, and as it flies forward.

In each case the wings are twisted upon themselves (screw fashion) in the direction of their length, and the tips of the wings describe figure-of-8 trajectories in space.

In Fig. 1, A, the horizon is indicated by the line *c*, *d*, and the direction of flight by the line *e*, *f*. The line *e*, *f* corresponds with the long axis of the body. The fly is seen from above and behind, and it will be observed that the reciprocating strokes of the wings indicated by the darts at *a* and *b* are more or less horizontal as compared with the long axis of the body. The blur or impression produced on the eye by the rapidly reciprocating wings is shown by the radiating interrupted lines which proceed from the roots of the wings as centres.

At Fig. 1, B, the body of the fly is seen in the same position as that shown at A. The fly is drawn in profile or from the side, and only the left wing and the blur produced by it, are seen. The letters are the same as in Fig. 1, A. In this case, the fly is poised or balanced in mid-air ; the wing making figure-of-8 trajectories parallel with the horizon (*c*, *d*) and nearly at right angles to the long axis of the body (*e*, *f*). The body is more or less vertical, the wing movements nearly horizontal. The fly has the power of balancing and maintaining its position by nicely adjusted, reciprocating wing movements similar to those practised by the kestrel when hanging, apparently motionless, over its fascinated and terror-stricken quarry. The fly can, however, by slightly increasing the speed and altering the pressure of the wings in certain parts of their course, instantly dart upwards as at *f*.

In Fig. 1, C, which gives a profile or side view of the fly, both the direction of the axis of the body and of the wing movements are changed. The direction of the long axis of the body (*c*, *d*) is horizontal, and the wing is striking downwards and forwards (*e*, *f*). The reciprocating movements made by the tip of the wing are indicated by the darts at *a*. Nothing is simpler than to alter the direction of the long axis of the body, and the direction of the stroke of the wing. The insect has only to make a slight change at the root of the wing to achieve both results. The roots of the wings are attached to the body by compound joints—universal in their nature—and their movements are regulated by voluntary muscles, and by springs, ligaments, and projections or stops, and are thoroughly under control. The slightest muscular movement brings about the desired result. The relations of the roots of the wings, and the wings as a whole, to the body is such, that the body in every possible position is mechanically adjusted and balanced, and swims about in space precisely as a compass set upon gimbals does. The same is true of the wings of birds, bats, and pterodactyls.

As a matter of fact, the roots of the wings of insects reveal highly complex arrangements. Not only can the wings be made to move in a horizontal and vertical direction, but at every degree of obliquity. They can also be folded and twisted in the direction of their length by voluntary muscular action when the wings are at rest, and when the air can take no part in producing the folding and twisting referred to. Of this I have fully convinced myself by repeated and careful observation. The movements of the wings of insects, and of birds and bats, are voluntary, controlled, and limited. They are inaugurated and completed by the volant animals, and are not, as is generally believed, due to the resistance and pressure exercised by the air when the wings are made to vibrate.

Natural flight, though largely, is not wholly, a mechanical problem. It is vito-mechanical, that is, mechanical plus life, plus intelligence. The volant animals arrange and regulate the details of flight. The flying machine will only become a success when the body and brain of the inventor are incorporated with it, and when the hands of the engineer, plus his intelligence, superintend and regulate the flying movements, whether produced by wings, aëroplanes, or screws.

The movements of the wings in the flight of the crane-fly are shown at Plate clxix., Figs. 2, 3, 4, and 5, p. 1234. The following is the account given of them in my notes taken in August 1879 :—

§ 398. Flight of the Crane-fly.

Have been studying the movements, and experimenting with the natural wing in the living crane-fly (daddy-long-legs), and have distinctly seen it twist its wing obliquely on its long axis to form a screw when at rest, and when the air could exercise no influence whatever in producing the movements of the posterior margin of the wing and of arranging the details of flight. The insect has therefore the power of twisting and untwisting its wing screw-fashion by a vital act in flight as apart from the resistance obtained from the air, and it is in virtue of this twisting and untwisting that the planes of the wing are reversed at the end of each oscillation of the wing. The wing is screwed and unscrewed in the air in flight, and it is the wing which sets the air in motion and not the air which sets the wing in motion. The power of twisting and untwisting the wing as it is made to vibrate resides in the muscles of the thorax, and I found that when the insect was dead I could produce a similar result, that is, a twisting and untwisting of the wing, by compressing or pinching the thorax laterally or from side to side. In the dead bluebottle-fly the wing can be elevated by depressing the upper part of the thorax with the head of a

pin. The construction of the wing and the joint at the root of the wing favour this view. The wing of the crane-fly consists essentially of four parts varying in thickness: (*a*) a stiffish anterior margin—the thickest part; (*b*) a flexible posterior margin (second thickest part), which is made to twist obliquely (screw-fashion) round the anterior margin; (*c*) a tip (the thinnest part), which can be compressed and slightly folded, corresponding to the part which folds in a beetle's wing when it is crumpled up beneath its elytron; and (*e*) a triangular portion with a cross joint at the root of the wing which seems to relieve the strain on it, allowing it to bend slightly. In the bluebottle there are two cross parts at the root of the wing, and these bend slightly on pressure. The root of the wing of the bluebottle consists of two parts, continuations of the anterior and posterior halves of the wing, and the wing can be twisted from the root into an elegant, flexible screw; the anterior and posterior halves plaiting, as it were, from the root. This arrangement admits of a partial folding in two directions, namely, in its length and breadth. It also admits (and this is important) of the wing twisting and untwisting obliquely on its long axis and so converting itself into a flexible screw. A somewhat similar arrangement is seen in the wings of the wasp.

The details of the construction of the wing of the crane-fly, taken by me from a natural fresh wing, are given at Plate clxix., Fig. 6, p. 1234.

The hinge at the root of the wing of the crane-fly is of the nature of a universal joint, so that it admits of

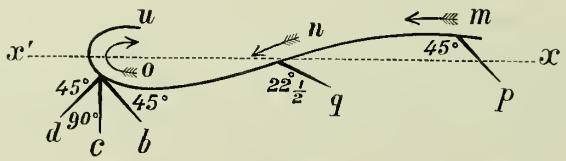


FIG. 511.

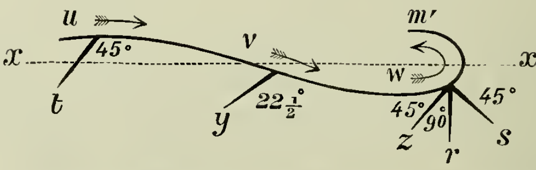


FIG. 512.

FIG. 511.—Trajectory made by the artificial insect wing from right to left. *x*, *x'*, The horizon; *m*, *n*, *u*, double-curve figure-of-8 track described by the wing when urged from right to left; *p*, angle made by the wing at the beginning of the stroke; *q*, ditto, made at the middle of the stroke; *b*, ditto, towards the end of the stroke; *c*, the wing in the act of reversing—at the reversing stage, the wing makes an angle of 90° with the horizon, and its speed is less than at any other part of its course; *d*, the wing reversed, and in the act of darting up to *u* to begin the stroke from left to right (*u*, *v*, *m'*) (the Author, 1870).

FIG. 512.—Trajectory made by the artificial insect wing from left to right. *x*, *x'*, The horizon; *u*, *v*, *m'*, double-curve figure-of-8 track described by the wing when urged from left to right; *t*, angle made by the wing with the horizon at the beginning of the stroke; *y*, ditto, at the middle of the stroke; *z*, ditto, towards the end of the stroke; *r*, the wing in the act of reversing—at this stage the wing makes an angle of 90° with the horizon, and its speed is less than at any other part of its course; *s*, the wing reversed, and in the act of darting up to *m'*, to begin the stroke from right to left (*m*, *n*, *u*) (the Author, 1870).

the wing being played vertically, horizontally, and obliquely. That the wing can be so played I have had the most convincing proof in the living insect. Thus I have seen it play its wings horizontally, obliquely, and more or less vertically. What especially struck me is the *concavo-convex* appearance presented by the blur of the rapidly moving wing—the concavity being directed upwards or forwards according as the anterior margin of the wing is directed upwards or forwards. Another point very noticeable was the alternate inclination forwards and backwards of the posterior margin of the wing at the end of each of its oscillations. The concavity of the blur or the impression produced on the eye by the rapidly oscillating wing is caused by the bending upwards, or upwards and forwards as the case may be, of its anterior margin. This bending is produced by the tractile force exerted by the tip of the wing; the wing, and more especially the part near its tip, always tending upwards, or upwards and forwards. It is also due in great measure to the varying angles made by the wing as it hastens to and fro—the angles being always least about the middle of the strokes—and to the figures-of-8 made by it as a whole. These points are illustrated at Plate clxx., Fig. 5, p. 1236; also at Figs. 511 and 512, which represent the horizontal oscillation or play of an artificial wing constructed in one piece on the insect type. The wing is shown in transverse section.

If an artificial, finely tapered, elastic wing, 2 feet long by 5 inches wide, with a semi-rigid anterior and highly elastic posterior margin, be constructed in one piece on the insect type, and the plane of the wing made to occupy a vertical position with the elastic posterior margin directed downwards, it will be found that if the wing be moved by the hand alternately from right to left and from left to right in a horizontal direction it makes a great variety of angles with the horizon; the angles being greatest when the wing is slowed preparatory to reversing, and least at mid-stroke, when the speed of the wing is greatest.

The wing, before it is made to move, makes an angle of 90° with the horizon. When made to move by the hand, say from right to left, it soon makes an angle of 45°; at the middle of the stroke it makes an angle of 20° or thereby; towards the end of the stroke, when it is being slowed preparatory to its being reversed, it

makes an angle of 45° ; when fully slowed it makes an angle of 90°, which is its position of rest. The same phenomena are repeated when the wing is made to travel from left to right. A remarkable property possessed by the artificial elastic wing is its power to reverse and change its direction at the end of each stroke. Thus the wing, when impelled from right to left, and when the stroke has been completed, suddenly turns a partial somersault from left to right, with the result that what was the under surface of the wing becomes its upper surface. There is a reversal of the planes of the wing—both surfaces of the more or less flattened wing of the insect being serviceable for the purposes of flight. The wing at the end of the right and left strokes reverses to a large extent mechanically and in spite of the operator. The reversal is primarily due to the slowing of the wing at the end of each stroke, to its elasticity, to its several parts travelling at different rates of speed, and to the anterior margin reversing before the posterior one ; an arrangement which begets continuity of motion and reduces the amount of slip in the wing to a minimum.[1] In the movements of the wing the resistance furnished by the air forms an important factor ; the resistance being greatest when the speed of the wing is highest, and the converse.

The remarkable feature in the artificial insect wing is its adaptability. It can be driven slowly, or with astonishing rapidity. It has no dead points. It reverses instantly, and in such a manner as to waste neither time nor power. It alternately seizes and evades the air so as to extract a maximum amount of support with a minimum of slip, and with a minimum expenditure of power. It supplies a degree of buoying and propelling power which is truly remarkable. Its buoying area is nearly equal to half a circle. It can act upon still air, and it can create and utilise its own currents. I proved this in the following manner. I caused the wing to make a horizontal sweep from right to left over a lighted candle. The wing rose steadily as a kite would, and after a brief interval the flame of the candle was persistently blown from right to left. I then waited until the flame of the candle assumed its normal perpendicular position, after which I caused the wing to make another and opposite sweep from left to right. The wing again rose kite fashion, and the flame was a second time affected, being blown in this case from left to right. I now caused the wing to vibrate steadily and rapidly above the candle, with this curious result, that the flame did not incline alternately from right to left and from left to right. On the contrary, it was blown steadily away from me, that is, in the direction of the tip of the wing, thus showing that the artificial currents produced met and neutralised each other always at mid-stroke. I also found that under these circumstances the buoying power of the wing was remarkably increased.

The artificial insect wing, like the natural wing, revolves upon two centres, and owes much of its elevating and propelling, seizing and disentangling power to its different portions travelling at different rates of speed, and to its storing up and giving off energy as it hastens to and fro. Thus the tip of the wing moves through a very much greater space in a given time than the root, and so also of the posterior margin as compared with the anterior. This is readily understood, by bearing in mind that the root of the wing forms the centre or axis of rotation for the tip ; while the anterior margin is the centre or axis of rotation for the posterior margin. The momentum, moreover, acquired by the wing during the stroke from right to left *is expended in reversing the wing*, and in preparing it for the stroke from left to right, and *vice versâ* ; a continuous to-and-fro movement devoid of dead points being thus established. If the artificial insect wing be taken in the hand and suddenly depressed *in a more or less vertical direction*, as in the bird and bat, it immediately springs up again, and carries the hand with it. It, in fact, describes a curve the concavity of which is directed downwards and forwards, and in doing so, carries the hand upwards and forwards. If a second down stroke be added, a second curve is formed ; the curves running into each other, and producing a progressive waved track in the air. This result is favoured if the operator runs forward so as not to impede or limit the action of the wing.

The direction in which the insect travels is determined by the direction of the stroke, by the pressure put upon the wing at various points, by the position of the body, and by the angles made by the wing and the body with the horizon from time to time.

The appearance presented by the rapidly vibrating wing of the crane-fly in upward, oblique, and forward flight is carefully delineated at Plate clxix., Figs. 2, 3, 4, and 5.

These figures also show how the wing twists in the direction of its length during its action, the range of the wing, the direction of the stroke, the position of the body, the shape of the blur caused by the wing, &c.

[1] If a rigid rod be made to vibrate, its movements are characterised by a pause or dead point at the end of each stroke. If a flexible elastic rod be employed, the pauses or dead points disappear. This follows because in the latter, opposite complementary double curves are developed, as in the natural wing, the rod reversing not as a whole, but by instalments. This is an important mechanical point, as it makes for continuity in wing movements.

PLATE CLXIX

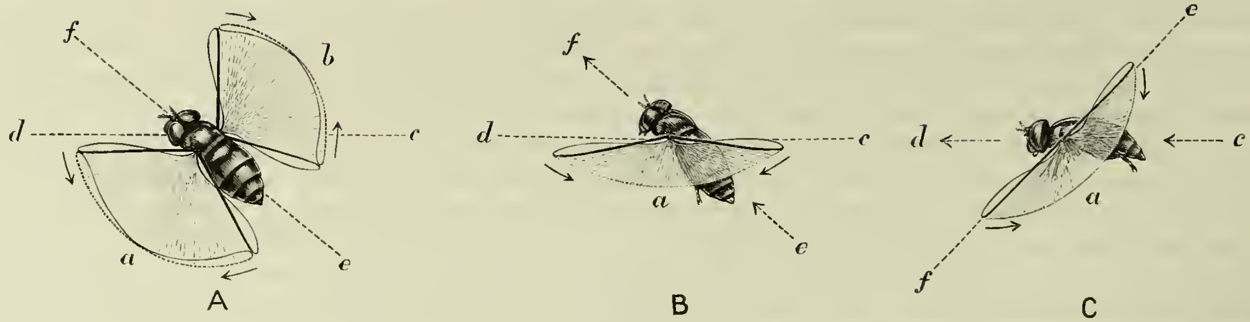


Fig. 1.

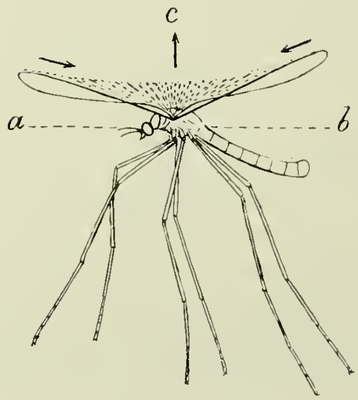


Fig. 2.

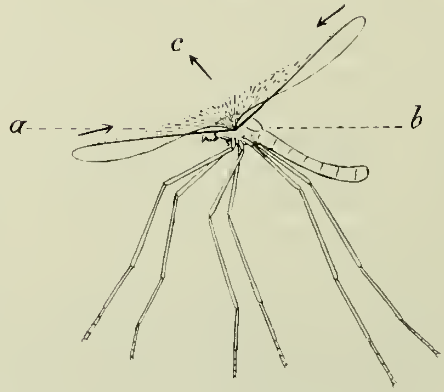


Fig. 3

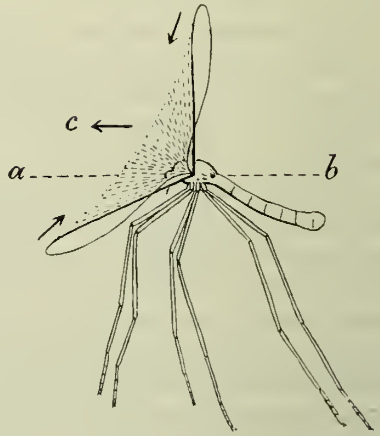


Fig. 4.

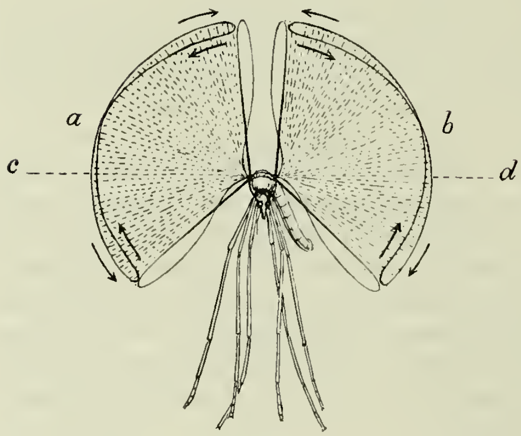


Fig. 5.

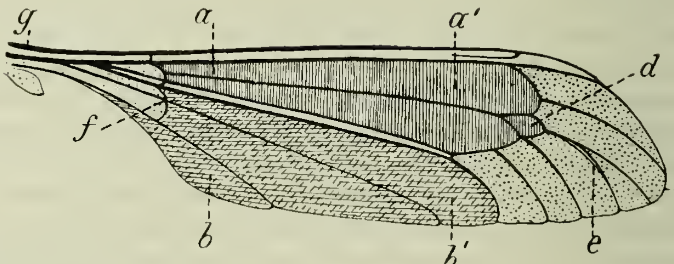


Fig. 6.

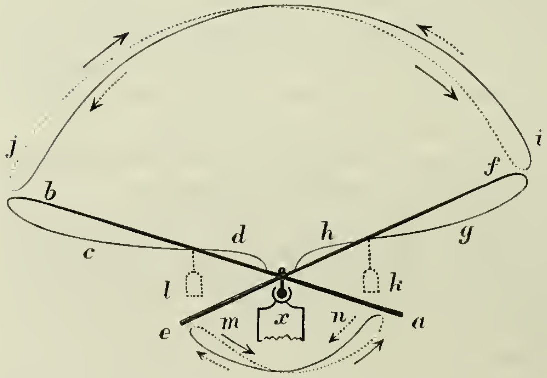


Fig. 7.

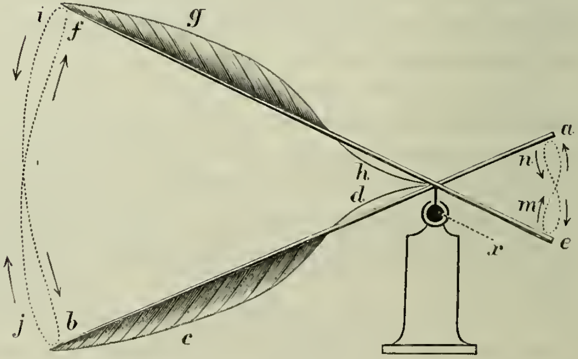


Fig. 8.

PLATE CLXIX

Plate clxix.—Shows the movements made by the wings in the flight of the common house-fly and the crane-fly; also the direction of the strokes made by the wings in upward, oblique, and horizontal flight as witnessed and delineated by the Author.

Fig. 1—A. Common house-fly, greatly enlarged to show the wing movements in upward flight. The fly is seen from above and behind. In this case the body is inclined upwards, and the wings, which are twisted in the direction of their length and making figure-of-8 tracks in space, are made to vibrate in the same plane as the body, giving what is a horizontal stroke as far as the body is concerned. *a, b,* The blur or impression produced on the eye by the rapidly oscillating wings; *e, f,* direction of flight; *c, d,* line representing the horizon.

B. Shows the common house-fly balanced or fixed in the air. The fly is seen from the side or in profile. In this case the body is directed obliquely upwards (*e, f*); the wings playing horizontally in the direction of the horizon (*c, d*). The blur made by the left wing is indicated at *a*. In balancing, the forward and backward strokes are made to counterbalance each other; the wings developing sufficient buoying power to maintain the insect at any desired point. The kestrel exerts the same power when hovering over a bird before pouncing on it.

C. Shows the common house-fly flying forwards. The fly is seen in profile. In this case the body is horizontal (*c, d*); the wings striking downwards and forwards (*e, f*). The blur made by the left wing is indicated at *a*. Fig. C gives the positions of the body and the wings of the insect when its greatest powers of flight are exerted. Its speed is equal to that of the swiftest horse.

Fig. 2.—Profile view of the movements made by the wings of the crane-fly in upward flight. In this, as in the common house-fly, the wings twist and untwist in the direction of their length, and make figure-of-8 tracks in space when made to vibrate. *a, b,* Line of horizon; *c,* direction of flight. By a twisting and untwisting, reciprocating, horizontal play of the wings, the body is forced vertically upwards as at *c*. The blur or impression produced on the eye by the rapidly moving wings is concave above.

Fig. 3.—Shows oblique upward flight of the crane-fly. *a, b,* Line of horizon; *c,* direction of flight. In this instance the wings are made to play in an oblique direction with reference to the horizon (*a, b*); the blur made by the wings being concave and directed upwards and forwards.

Fig. 4.—Shows forward flight of the crane-fly. *a, b,* Horizon; *c,* direction of flight. In this case the wings are made to play nearly vertically, the concavity of the blur made by the wings being directed forwards.

Fig. 5.—Shows the altogether vertical play of the wings of the crane-fly, seen when the posterior part of the body of the insect is held and it is attempting to get away. *a, b,* Blurs or impressions produced on the eye by the rapidly vibrating wings; *c, d,* line of horizon. In this case the wings are seen to twist and untwist as they hasten to and fro; their tips describing figure-of-8 tracks in space as indicated by the darts. The crane-fly has the power of changing the direction of the strokes made by its wings at pleasure, and it is no uncommon thing to see the insect playing its wings in all the positions indicated in the figures.

Fig. 6.—Anatomy of the wing of the crane-fly—the wing greatly enlarged the better to show the structure. The wing of the crane-fly, like that of other insects, is composed of a duplication of the wing membrane, supported by hollow horny tubes (nervures) which run in the direction of the length of the wing anteriorly, and which radiate obliquely backwards in the direction of the posterior margin. The wing is graduated and tapers; being thickest at the root and along the anterior margin, and thinnest at the tip and along the posterior margin. The strongest parts of the wing are seen at *g, a, a'*; the thinner parts at *b, b'*; and the thinnest at *c*. At *d* and *e* the wing can fold slightly in a transverse and longitudinal direction; while at *f*, there is a transverse quasi-joint which gives greater mobility to the wing action. The wing, as will be seen, may be divided into four portions; each portion being indicated by different shading, the more readily to catch the eye. The root of the wing is provided with a compound joint (universal in its nature) which admits of the wing being made to oscillate in an upward, downward, forward, and backward direction, or at any degree of obliquity. The drawing is too small to show the joint.

Fig. 7.—Artificial wing, showing how the twisting and untwisting of the natural wing are produced, and also how the horizontal figure-of-8 movements of the natural wing, seen at Fig. 2, can be correctly imitated. *a, b, c, d,* The artificial wing twisted upon itself at the end of the forward horizontal stroke raising a weight (*l*); *e, f, g, h,* the same wing as seen at the end of the back stroke raising a weight (*k*); *x,* ball-and-socket or universal joint by which the artificial wing is hinged; *m, n,* figure-of-8 movements made by the root of the wing, which produce similar movements (*i, j*) in the tip of the wing. The weights raised correspond with the body of the natural insect.

Fig. 8.—Artificial wing, showing how the vertical figure-of-8 movements made by the natural wing at Figs. 4 and 5 may be reproduced. The letters are the same as in Fig. 7, and the movements made by the artificial wing are identical with those made at Fig. 7, allowance being made for the difference in the direction of the stroke. *g,* Appearance presented by the wing at the beginning of the down stroke; *c,* the same at the end of the down stroke. The other letters have the same value as at Fig. 7. (The figures in this plate were drawn by the Author from natural and artificial wings in motion.)

PLATE CLXX

Plate clxx.—Shows how the wings of insects, birds, and bats make figure-of-8 trajectories in the air when the volant animals are fixed, and how the figures-of-8 are opened out or unravelled to form undulating or waved trajectories when the volant animals are flying rapidly forward in space; how the wings twist and untwist in the direction of their length and form figure-of-8 tracks when made to oscillate; how the insect plays its wings in a more or less horizontal direction, the bird and bat playing theirs in a more or less vertical direction; how the bodies of volant animals in flight are carried along a curved line, the bodies being elevated with every descent of the wings, and falling temporarily through short distances every time the wings ascend.

PLATE CLXX

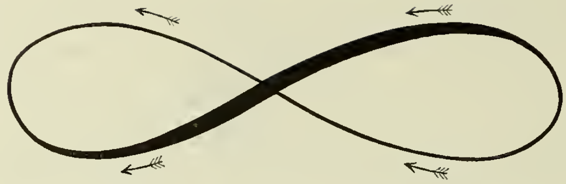


FIG. 1.

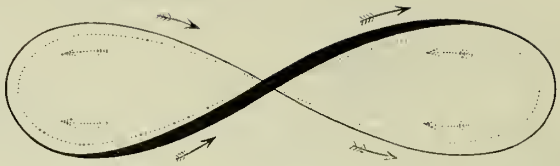


FIG. 2.

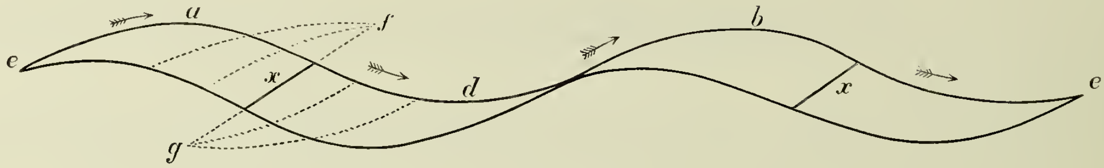


FIG. 3.

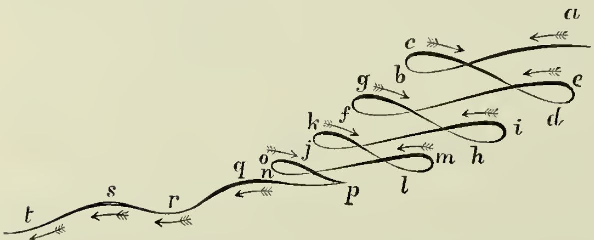


FIG. 6.

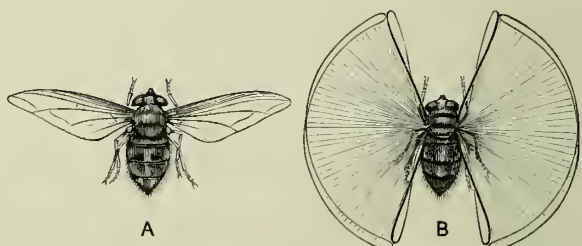
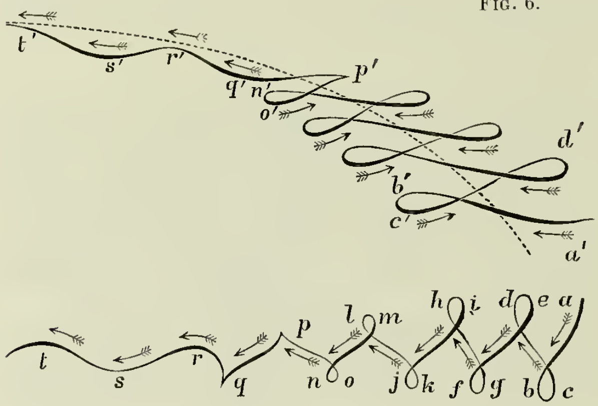


FIG. 4.



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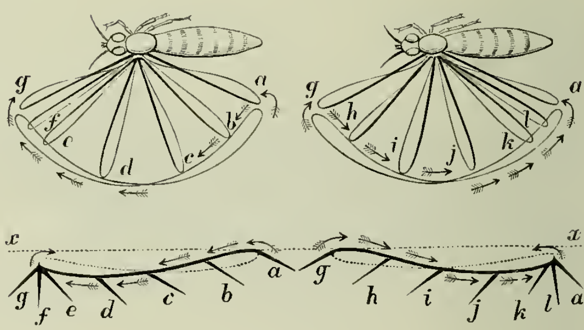


FIG. 5.

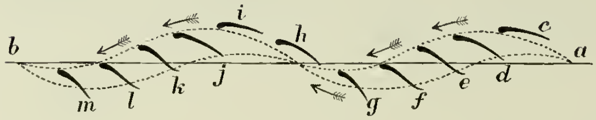


FIG. 8.

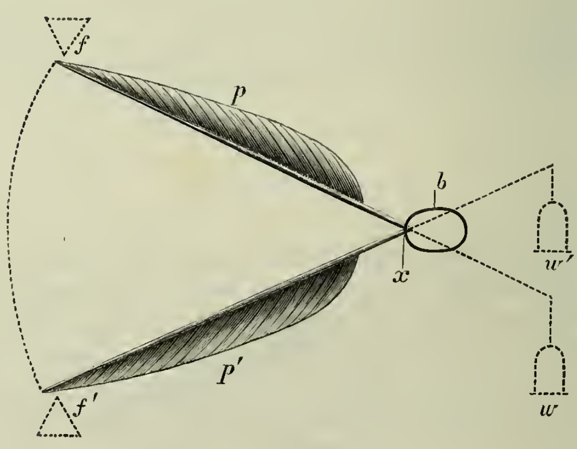


FIG. 9.

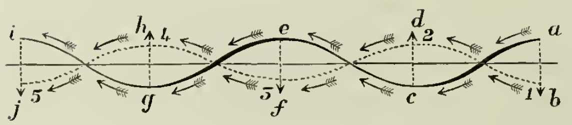


FIG. 10.

PLATE CLXX—*continued*

FIG. 1.—Figure-of-8 trajectory made by the margins and tip of the wing of the insect in *extension*. The arrows indicate the direction of travel. These movements are reversed during *flexion;* the wing *crossing its own track* during extension and flexion (the Author, 1867).

FIG. 2.—Complementary portion of Fig. 1. In this figure the dotted line and the dotted arrows indicate the figure-of-8 made by the margins and tip of the wing during *flexion*. The arrows in the completed figure point in opposite directions, and show the reversing, reciprocating movements made by the wing during its vibration (the Author, 1867).

FIG. 3.—While the figure-of-8 accurately represents the trajectory made by the wing in the air when the volant animal is fixed, it is quite otherwise when the animal is rapidly flying forward. In this case, the wing, in virtue of its being carried forward by the body in motion, describes first a looped and then an undulating or waved track. *e*, *e*, Line of horizon ; *a*, *b*, down strokes of wing ; *c*, *d*, *e*, up strokes of wing; *f*, posterior margin of wing rotating downwards and increasing the angle (*x*) made by it with the horizon during the down stroke; *g*, posterior margin rotating upwards and decreasing the angle made with the horizon prior to the up stroke (the Author, 1867).

FIG. 4.—The blow-fly with its wings at rest and when made to vibrate rapidly.

A. The blow-fly at rest. Its wings are triangular, elastic, carefully graduated, and very ample, considering the size of the insect.

B. The blow-fly playing its wings at a high speed. The wings, under these circumstances, twist and untwist screw-fashion ; their tips describing figure-of-8 trajectories in the air. Each wing sweeps through three-fourths of a circle in its reciprocating movements, and, as the wings are comparatively very long, the area covered by them is very large. The area or blur, for the two are co-extensive, provides practically a solid basis of support for the body, from the fact that the movements of the wings are so rapid that they are to all intents and purposes in every part of the area at the same time. This is a matter of great importance, and satisfactorily accounts for the splendid flying powers possessed by the insect (the Author, 1879).

FIG. 5.—The upward two figures show the twisting and untwisting and the horizontal figure-of-8 movements made by the wing of the wasp. The forward stroke of the wing is indicated at *a*, *b*, *c*, *d*, *e*, *f*, *g*, the backward stroke at *g*, *h*, *i*, *j*, *k*, *l*, *a*. The angles made by the wings with the horizon (*x*, *x*) during these strokes are indicated in the two lower figures at *a*, *b*, *c*, *d*, *e*, *f*, *g* ; *g*, *h*, *i*, *j*, *k*, *l*, *a*. It will be observed that these angles vary at every stage of the forward and backward strokes, being greatest at the end of the strokes, when the movements of the wing are slowed prior to the wing reversing, as shown at *e*, *f*, *g* and *k*, *l*, *a* respectively. The angles are least at the middle of the strokes, when the speed of the wing is greatest, as indicated at *c* and *i*. As the wings during the forward and backward movements draw currents of air after them which are being constantly met, the insect flies largely on artificial currents of its own forming. This is one of the peculiarities of reciprocating wing and other structures (the Author, 1870).

FIG. 6.—Upper figure : shows how in free and rapid flight the horizontal figure-of-8 movements made by the wing of the insect in captive flight are opened out or unravelled to form first a looped and then an undulating or waved track. This unlooked-for result is brought about by the rapid forward travel of the body in free flight preventing the wings from retracing and completing the posterior loops of the 8. The letters from *a* to *p* inclusive indicate the figure-of-8 looped path pursued by the wing prior to the looped path being converted into the waved path indicated at *p*, *q*, *r*, *s*, *t*. The horizontal, forward, figure-of-8 screwing of the wing in a slightly downward direction is accompanied by a figure-of-8, looped, and waved recoil in a slightly upward direction, communicated to the body of the insect as seen in the lower figure, where the letters are the same as in the upper one, with the addition of dashes (the Author, 1870).

FIG. 7.—Shows how in the bird and bat in rapid free flight, the vertical, figure-of-8 movements made by the wing in captive flight are opened out to form first a looped and then a waved track, as in the insect. The lettering is the same as in the upper figure of Fig. 6.

FIG. 8.—Gives an analysis of the movements made by the wing of the bird and bat during the down and up strokes as seen on transverse section of the wing. It brings out the important facts: (*a*) that both during the down and up strokes the concave surface of the wing is directed towards the horizon at an upward angle, acting as a true kite in both cases ; and (*b*) that the wing makes a great number of angles with the horizon during the down and up strokes. This arrangement increases the elevating and propelling power of the wing to a maximum, and decreases the amount of slip to a minimum. The wing during both the down and up strokes is a kite flying forward ; the wing hugging and biting the nether air with its concave surface during the down stroke, and throwing off and eluding the superincumbent air by its convex surface during the up stroke. *a*, *b*, Line of horizon ; *c*, *d*, *e*, *f*, down stroke of wing ; *g*, *h*, *i*, up stroke of wing ; *j*, *k*, *l*, second down stroke ; *m*, beginning of second up stroke (the Author, 1870).

FIG. 9.—Artificial wing, showing how the wing of the bird and bat act in a more or less vertical direction in captive flight, and how the wing rotates on its anterior margin as an axis during the down and up strokes. *p*, Upper or convex surface of the wing as seen at the beginning of the down stroke ; *p′*, lower or concave surface of the wing as seen at the end of the down stroke. The change of surface is due to the wing rotating along its anterior margin as it descends. The downward movement, when rapid, begets a twisting of the wing in the direction of its length. *f*, *f′*, Fulcra formed by the air on which the wing acts ; *x*, universal joint by which the wing is attached to the body (*b*); *w*, *w′*, weights which represent the body and are lifted by the wing (the Author, 1874).

FIG. 10.—Shows the double waved trajectory made by the wings and body of a volant animal in free forward flight. When the wings descend, the body is elevated; when the wings are elevated, the body falls slightly. While the body is directly elevated by the wings, it in turn by its fall contributes to the elevation of the wings. In this way, weight assists in flight. The vertical darts *a*, *b* ; *c*, *d* ; *e*, *f* ; *g*, *h* ; *i*, *j*, indicate the beats of the wing during the down and up strokes ; the letters *a*, *c*, *e*, *g*, *i*, mark the undulating or waved trajectory made by the wing ; Figs. 1, 2, 3, 4, 5, showing the alternate and opposite waved trajectory made by the body. It will be observed that the waved trajectories made by the wings and body alternately cross each other at stated intervals (the Author, 1870).

THE WINGS OF BIRDS

§ 399. Structure and General Appearance presented by the Wing of the Bird.

Having described and delineated the shape, structure, and movements of the wing of the insect, and spoken of wings and wing movements generally, we are now in a position to deal with the wing of the bird from the anatomical side.

The wing of the bird, like that of the insect, is triangular in shape, elastic, and finely graduated ; it being thicker at the root and along the anterior margin and thinner at the tip and along the posterior margin. The bones of the wing run along the anterior margin ; the feathers, engaged in flight, along the posterior margin. The whole wing is covered with small, soft feathers ; the posterior margin being provided with large, stiffish, highly elastic feathers. The large feathers engaged in flight are divided into three sets, namely, the primary or rowing, the secondary, and the tertiary. The primary feathers occupy the tip, and nearly the outer half of the wing posteriorly, and are the longest and strongest ; the secondary feathers occupy a position next to the primaries on the posterior margin, and are next in length and strength—the tertiary feathers, occurring at the root of the wing, being larger and longer than the secondaries, but softer and weaker.

The primary feathers are usually nine in number, and they diminish in length and strength as they approach the secondaries. The secondaries are also graduated, those near the root being more feeble than those next the primaries. The tertiary feathers occur as a triangular patch near the root, and are larger, longer, and softer than the secondaries.

The primary, secondary, and tertiary feathers are convex above and concave below, and assist in conferring on the wing its concavo-convex form ; this form being completed by the bones, muscles, and elastic structures of the wing. The concavo-convex form of the wing is more pronounced than a superficial examination would lead one to expect. As the resistance of a concave over a convex surface is as two to one, it follows that the concavo-convex form of wing is the best possible for alternately seizing and letting go the air during the down and up strokes in rowing flight.

The primary, secondary, and tertiary feathers overlap and slate each other on one side, and have a valvular action, so that they can be opened up and separated during flexion and the up stroke of the wing in such a way as to present so many knife edges to the superimposed air which they thereby successfully elude, while during extension and the down stroke they come together, close, and present an unbroken surface which enables the wing effectually to seize the nether air. The valvular action of the wing during the up and down strokes is supplemented by another mechanical contrivance of great value in flight. When the feathers of the wing are separated and opened up in flexion and the up stroke, the length of the wing is greatly curtailed, and it is elevated as a short lever. When, on the other hand, the feathers of the wing are closed and banded together in extension and the down stroke, the length of the wing is increased by about a half, and is depressed as a long lever. The fight which the wing wages with the inexorable law of gravitation is further materially aided by the down stroke of the wing being delivered with much greater force than the up stroke, and by the concavity or biting surface of the wing being always directed downwards during the down stroke.

The primary, secondary, and tertiary feathers of the wing of the bird are differentiated to quite an extraordinary extent, and exhibit unmistakable evidence of design, and this evidence is greatly increased by the general shape, the concavo-convex form, and the carefully graduated nature of the wing and wing movements. It is further augmented by the beautiful spiral arrangements of the bones, joints, and muscles of the wing, by the elastic structures, and by the marvellous modification, for the purposes of flight, of the wrist and finger bones of the wing, whereby certain bones are suppressed, and others are enlarged and fused together to form a flat, osseous platform for supporting the roots of the primary or rowing feathers.

While the wings of all birds are triangular in shape, it is proper to mention that they vary considerably in general outline. Thus the wings of the barn-door fowl, turkey, capercailzie, pheasant, grouse, and partridge are short, broad, deeply concavo-convex, and rounded at the tip ; the wings of the falcons and hawks are comparatively long, less concavo-convex, and pointed at the tip. The wings of the vulture, swan, heron, and crane are intermediate both as regards the degree of concavity and the rounding of the tip. The wings of sea-birds are frequently very long, narrow, flattish, and pointed, as in the albatross,[1] frigate bird, gannet, tern, and some gulls ; the wings of swifts and swallows are long, narrow, scythe-like, and sweeping. Other forms may be mentioned, such as the raven, crow, wild duck, and woodcock, where the wings are more decidedly triangular, the tip being more or less pointed ; and the magpie, water-hen, and grebe, where the tip is rounded.

[1] I have in my collection an albatross wing which is 6 feet in length and only 8 inches in breadth.

The shape of the tip of the wing is determined by the length of the primary feathers forming it.

In the true falcons, the albatross, swift, swallow, and humming-bird, the first primary feather is longest and strongest. In the gannet, wild duck, goose, pigeon, owl, and gull, the second primary feather is longest and strongest; whereas in the barn-door fowl, turkey, capercailzie, pheasant, and grouse, the third primary is longest and strongest.

The short, broad, deeply concavo-convex wings rounded at the tip are driven at much higher speeds than the longer, narrower, flatter, pointed wings; the rule being, that the short, broad, rounded wings are associated with heavy bodies, great muscular exertion, short flights, and non-skimming flights, while the longer, narrower, flatter, pointed wings are associated with proportionally lighter bodies, moderate muscular exertion, protracted flights, and skimming flights.

The perfection of skimming or sailing flight is seen in the albatross, this majestic bird floating about near the surface of the Southern Ocean, occasionally for a whole hour without once deigning to flap his magnificent pinions, which stream from him on either side and cover, in some instances, an area of 15 feet or thereby.

The wings of the albatross are comparatively flat, and their under surfaces act as true kites in sailing flight.

Most birds can skim for short distances, but it is only the birds with long, narrow, pointed wings which are masters in this most difficult field of wingmanship.

The rule is, that the birds with short, broad, deeply concavo-convex, rounded wings make the air currents themselves, on which they rise and progress; whereas the birds with long, narrow, flatter, pointed wings utilise existing air currents, which, needless to say, is an enormous saving of muscular exertion.

In flight one of two things is necessary. Either the wings of the volant animal must be driven at a high speed in still air, or the air must be moving at a high speed and the extended wings held out motionless. Moving air is a necessity in flight. It must be set in motion by the wings, or, being in motion, the extended motionless wings must rest upon it as upon two kites buoyed up by it. A canary when it flies in a room with doors and windows closed causes its wings to go whirr, whirr with immense velocity for short intervals: in the open, on the contrary, in a steady, stiff breeze, the gull and gannet can skim about with extended, motionless wings in any direction, and apparently with no effort, for indefinite periods.

I append careful drawings from nature of typical wings in my collection. In each case the wings are drawn according to scale, and each feather is correctly given. See Plates clxxi. and clxxii.

PLATE CLXXI

Plate clxxi.—Shows various typical wings, including those of the pheasant, partridge, heron, wild duck, kestrel, diver, and gull. The pheasant, partridge, and heron illustrate the deeply concavo-convex form of wing; the kestrel the flat form of wing; and the wings of the wild duck, diver, and gull furnish examples of intermediate forms. (The figures in this plate are drawn from nature by C. Berjeau and the Author for the present work.)

FIG. 1.—Wing of the pheasant (*Phasianus colchicus*). Illustrates the short, broad, deeply concavo-convex form of wing rounded at the tip. *a, b, c,* Anterior margin of wing; *d, e, f,* posterior margin of wing. The anterior margin is formed of feathers, bones, muscles, and elastic structure, and is semi-rigid; the posterior margin is formed by the primary feathers (*d*), the secondary feathers (*e*), and the tertiary feathers (*f*), and is highly elastic.

FIG. 2.—Wings of the partridge (*Perdrix cinerea*) as seen in rapid flight. This figure shows the deeply concave under surface of the wings, which form an upward angle with the horizon and act as true kites. The partridge affords an example of a heavy, powerful bird with small wings—the wings in flight being driven with immense velocity.

FIG. 3.—Wings of the heron (*Ardea cinerea*). This figure affords an example of long, broad, deeply concavo-convex wings fairly round at the tip. The under concave surfaces of the wings are seen to great advantage. They exert a kite and parachute action in flight. The heron furnishes an example of a light, comparatively weak bird with very large wings.

FIG. 4.—Wings of the kestrel. The upper of the two figures shows the dorsal surface of the wing. It provides an example of a narrow, flattish, pointed wing, and is exceedingly efficient in flight; the kestrel being noted for its superlative wingmanship and complete command of the air. *d, e, f,* Anterior margin of wing; *c, a, b,* posterior margin of wing. The primary feathers (*b*) of the wing of the kestrel are strong and very beautifully formed. The secondary feathers are seen at *a*, and the tertiary ones at *c*. The lower of the two figures shows the wing as seen from above and behind. It reveals the dorsal (*d, c*) and ventral (*f, b*) surfaces of the wing; the posterior margin (*c, b*) making a double-*f* curve round the anterior margin (*d, f*) as an axis. The wing in the position drawn forms a screw resembling that of an ordinary ship propeller.

FIG. 5.—Wing of the wild duck. This wing is more triangular in shape than that of the kestrel. It is pointed and intermediate as regards its convexity and concavity. It is a very powerful, finely balanced wing; the wild duck, when once fairly launched in space, flying with incredible velocity. *a, b, c,* Anterior margin of wing; *d, e, f,* posterior margin of wing. The primary feathers are seen at *d*, the secondary feathers at *e*, and the tertiary feathers at *f*. *g*, Wing covert.

FIG. 6.—Ellipse made by the tip of the wing of the bird during flexion and the up stroke, and extension and the down stroke. The interrupted curved line and dart indicate the former; the solid curved line and dart the latter. The dotted straight line indicates the axis round which the curved spiral movements occur.

PLATE CLXXI

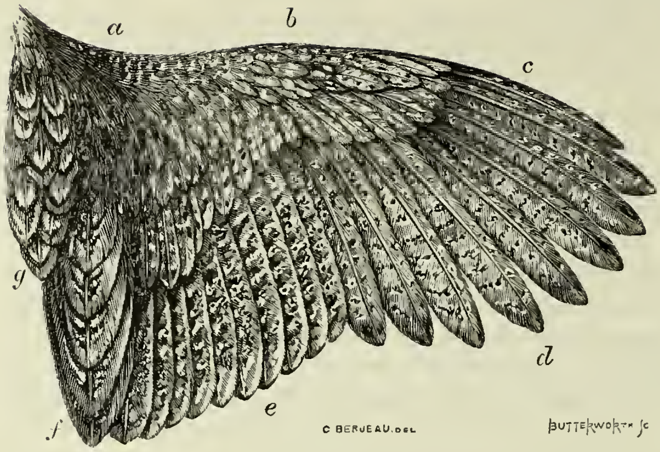


Fig. 1.

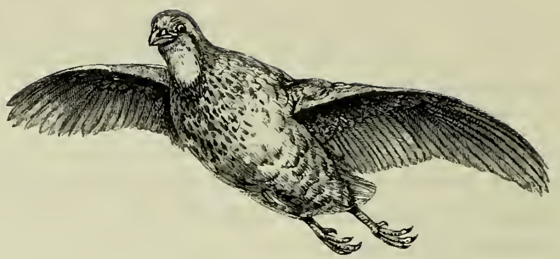


Fig. 2.

Fig. 3.

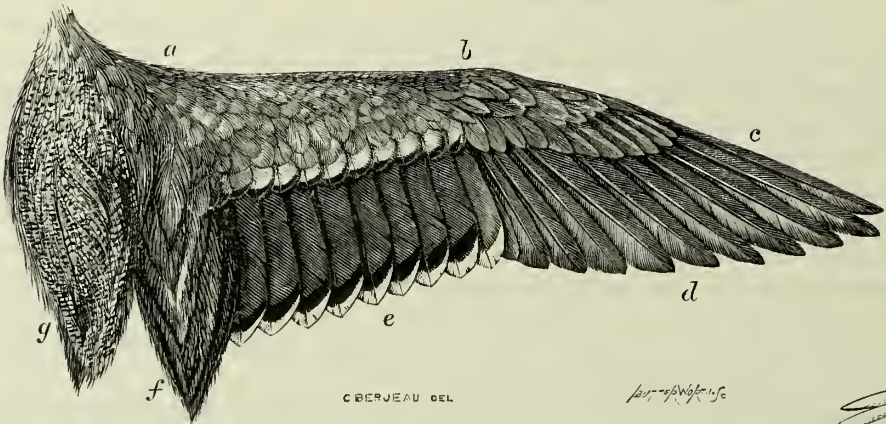


Fig. 5.

Fig. 6.

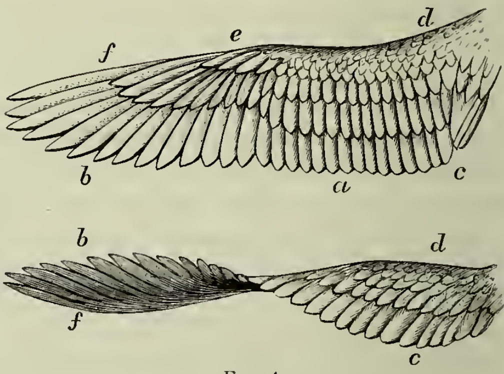


Fig. 4.

Fig. 7.

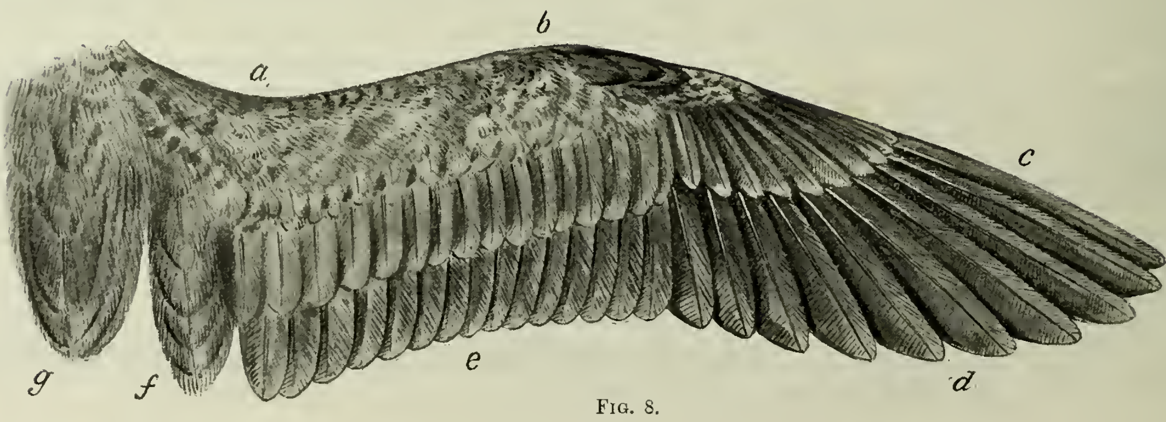


Fig. 8.

PLATE CLXXII

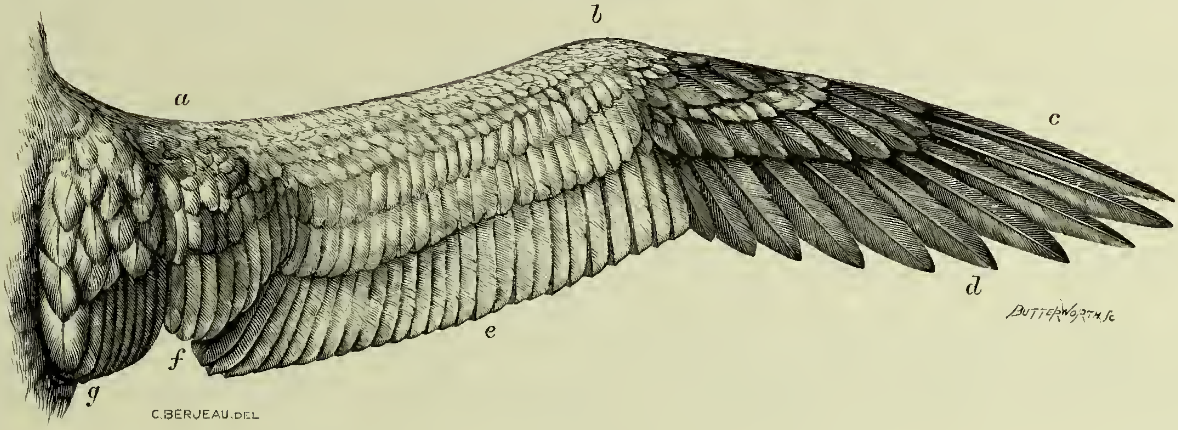


FIG. 1.

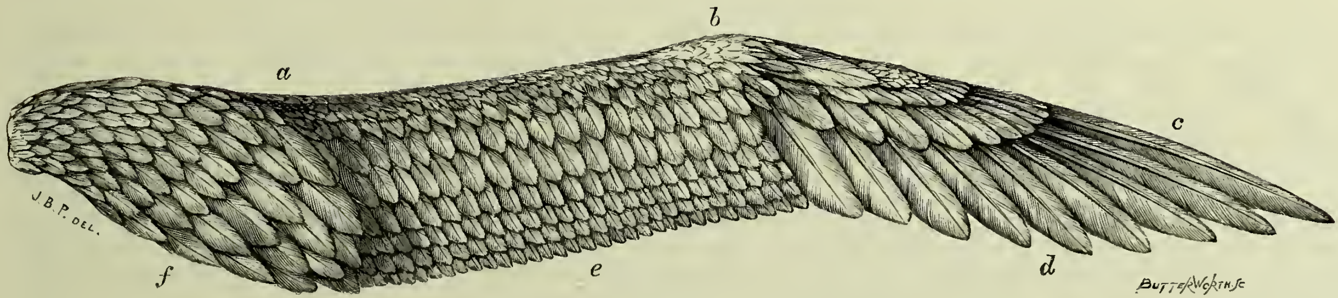


FIG. 2.

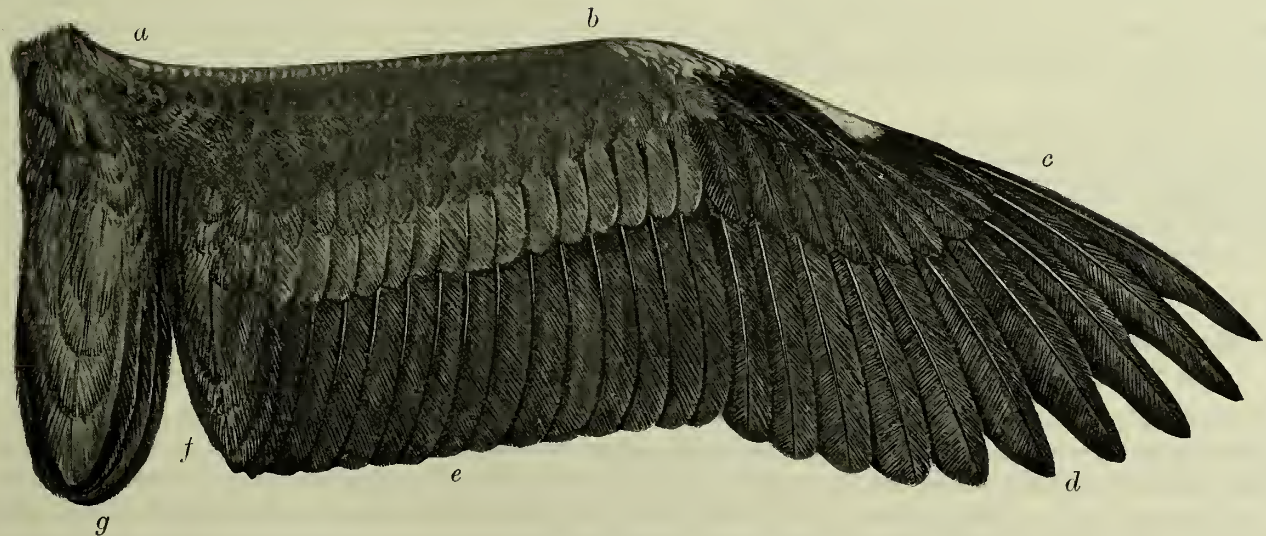


FIG. 3.

PLATE CLXXI (*continued*)

Fig. 7.—Wing of the diver or murrat. This wing is remarkable for its small size and narrowness. It is a well-formed wing, neither pointed nor rounded at the tip, and moderately concavo-convex. The diver, on the whole, affords the best example of a heavy-bodied, small-winged, flying bird ; the dabchick or lesser grebe coming next. The wings of the diver, compared with the body, are so small that the bird has great difficulty in rising from the water. In order to obviate this difficulty it faces the breeze on getting up so as to take advantage of the moving air, which playing on the under concave surface of the wings assists their kite action. The wings are driven at a furious pace, and the bird travels at incredible speed near the surface of the sea in straight lines or in wide curves. When its flight is over, it drops into the water with a splash like a small cannon ball. The body of the diver weighs 2 lbs., and each wing only measures 11½ ins. in length and 3½ ins. in breadth. The body and wings of the diver are to be contrasted with the body and wings of the grey gull, which also weighs 2 lbs. The wing of the grey gull is given at Fig. 8.

Fig. 8.—Wing of the grey gull. This is a long, ample, moderately concavo-convex wing, neither round nor pointed at the tip. It greatly resembles the wing of the diver in its general shape. It is, however, more than four times the size of the diver's wing. This is a very remarkable circumstance, as the bodies of the grey gull and diver each weigh 2 lbs. The difference is accounted for by the wings of the grey gull being driven very slowly ; those of the diver being driven at phenomenal speed. Flight resolves itself into heavy body, small wings, and rapid wing movements, or light body, large wings, and slow wing movement. It is a question of weight and increased power versus levity and diminished power. The flight of the gull consists of flapping or rowing and skimming or sailing. In a good breeze the gull flaps its wings seldom, and sails about with great ease and grace. Sailing flight requires large wings and a comparatively light body. The wings of the grey gull measure 25 ins. in length, with an average breadth of 7 ins. My estimate of the wing capacity and weight of the diver and grey gull respectively was taken from fresh specimens, and is therefore reliable. *a, b, c,* Anterior margin of wing ; *d, e, f,* posterior margin of wing, consisting of primary (*d*), secondary (*e*), and tertiary (*f*) feathers ; *g*, wing covert.

PLATE CLXXII

Plate clxxii.—Illustrates long, narrow, moderately concavo-convex wings, semi-pointed and pointed at the tip, as seen in the gannet and albatross : also long, broad, deeply concavo-convex wing, rounded at the tip, as witnessed in the heron. (The figures in the plate are drawn from nature by C. Berjeau and the Author for the present work.)

Fig. 1.—Wing of the gannet (*Sula bassana*). This is a long, powerful, semi-pointed wing, moderately concavo-convex. The primary feathers are especially strong and well formed, and the wings are well calculated to make long, fatiguing journeys to and from the feeding areas. The flight of the gannet consists of combined rowing and sailing movements—the latter predominating. It is a most interesting sight to watch a gannet fishing. When it finds its quarry it glides up on the wind and then, suddenly changing its course, it plunges head foremost into the sea as if it were a mass of lead. It seizes its prey and continues its flight under the water, from which it emerges at a considerable distance. The downward plunge of the bird is so rapid that a beautiful white spray of water is thrown up to an altitude of six or more feet. At the breeding season, on the Bass Rock, Scotland, the birds are so tame that I have watched their flight at not more than six or eight feet from me. *a, b, c,* Anterior margin of wing ; *d, e, f,* posterior margin of wing, consisting of primary (*d*), secondary (*e*), and tertiary (*f*) feathers ; *g*, wing covert.

Fig. 2.—Wing of the albatross (*Diomedea exulans*). This is the most striking and powerful of all the long, narrow, pointed wings. It is moderately concavo-convex. Like the wing of the gannet, its primary feathers are remarkably strong and well formed. The wing of the albatross is at once the longest and narrowest of modern wings. It measures over six feet in length and is not more than eight inches in breadth. The albatross is a large, heavy bird, but its enormous pinions bear it aloft with the greatest ease, even in light breezes. The bird, when settled on the water, makes immense efforts to get into the air by beating the water vigorously with its wings. When once fairly launched in space, it is completely master of the situation, and has been known to sail about for a whole hour without once flapping its wings. The albatross has no rival in sailing flight. The lamergeyers and vultures are, however, not far behind. These sometimes attain an altitude of over six miles, and float about for hours together with apparently little or no effort. *a, b, c,* Anterior margin of wing; *d, e, f,* posterior margin with its primary (*d*), secondary (*e*), and tertiary (*f*) feathers.

Fig. 3.—Wing of the heron (*Ardea cinerea*). This is one of the best examples of a long, broad, deeply concavo-convex wing rounded at the tip. Its primary, secondary, and tertiary feathers are weak as compared with corresponding feathers in the wings of the gannet and albatross. It is, compared with the size of the body of the bird, a very large wing. The heron provides one of the best examples of a light-bodied, large-winged bird. Its flight is very slow, almost solemn. I have often timed the beat of the wings. The beats are exactly sixty to the minute. The bird flies with a slow, steady, flapping movement. It rarely attempts to skim even for short distances.

§ 400. Movements of the Wing of the Bird—Flexion and Extension of the Wing—Valvular Action of the Primary and Secondary Feathers.

Flexion and extension and the valvular action of the primary and secondary feathers form integral and important parts of the movements of the wing of the bird, inasmuch as they furnish a means whereby the wing can evade the superimposed air during flexion and the up stroke and seize the nether air during extension and the down stroke.

The valvular action of the feathers is only elicited during the flexion and extension of the wing in active rowing flight, when the wing is suddenly pulled together and flexed and the primary and secondary feathers separated and thrown out of gearing to let the air pass between them, and when the wing is suddenly shot out or extended and the primary and secondary feathers are closed and banded together to prevent the escape of the air.

There is a popular belief that the wing is only flexed or folded when it is tucked up on the back of the bird

to be out of harm's way, and that in flight the wing is always extended. This, however, is a mistake. The flexion of the wing and the separation of the primary and secondary feathers during the up stroke, and the extension of the wing and the closing and banding together of the said feathers during the down stroke, are integral and necessary parts of flight in all birds. This is proved beyond doubt by instantaneous photographs of flying birds. (See Plate clxv., Fig. 6, p. 1198.)

The arrangements for folding and extending the wing and for opening and closing the primary and secondary feathers during the up and down strokes are of the most elaborate description. They form part of a highly complex system of inherent wing movements, and, in order to understand them, it is necessary to describe wing movements as a whole.

On examining the wing of a living bird it is found that it is attached to the body by a loose ball-and-socket or universal joint which admits of upward, downward, forward, backward and oblique movements, with rotatory movements along the anterior margin of the wing. The rotatory movements extend to the root of each primary and secondary feather ; the feathers rotating in one direction when they open up to let the air pass between them in the up stroke, and rotating in another and opposite direction when they close and band together to prevent the air escaping during the down stroke. The wing is flexed and elevated and extended and depressed by the action of voluntary muscles, but these movements can be readily produced artificially in the living bird. The muscles cause the hand of the bird to fold on the forearm at the wrist, and the forearm to fold on the arm at the elbow joint ; the wrist and elbow joints, and the bones forming the arm, forearm, and hand being spiral in their nature. The muscles are connected, in many cases, with an elaborate system of fibro-elastic ligaments which are largely responsible for flexing the wing during the up strokes. These fibro-elastic ligaments are put upon the stretch by the voluntary muscles during extension and the down stroke. They assist the wing over its dead points at the end of flexion and extension and during the up and down strokes, and convert its movements into voluntary vito-mechanical movements.

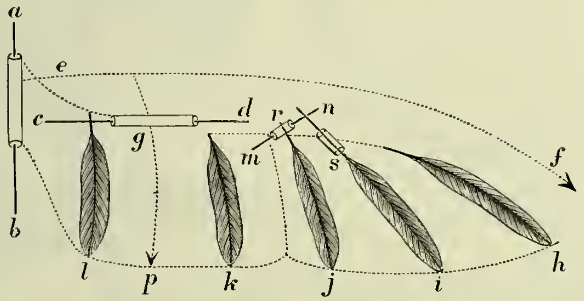


FIG. 513.—Diagram of the wing of the bird. *a*, *b*, Axis of rotation for the root of the wing with radius *e*, *f* ; *c*, *d*, axis of rotation for the anterior margin of the wing with radius *g*, *p* ; *n*, *s*, axis of rotation for the primary feathers in the direction of their length ; *m*, *r*, transverse axis for the bending of the same feathers at their roots ; *h*, *i*, *j*, primary feathers ; *k*, *l*, secondary feathers (the Author, 1870).

In flight flexion occurs principally at the wrist joint, the result being to reduce the length of the wing by about a half. The wing is, consequently, elevated as a short lever with the primary and secondary feathers separated and open, and depressed as a long lever with the same feathers pressed together and closed. The shortening and elongating of the wing and the opening and closing of the primary and secondary feathers are potent factors in alternately eluding and seizing the air during the up and down strokes.

From the foregoing it will be evident that the living wing, when it is being flexed and elevated, and extended and depressed, and its primary and secondary feathers opened and closed during flight, is moving in all its parts at one and the same time.

The upward and downward movements of the wing, its rotation along its anterior margin, and the rotation of the primary and secondary feathers at their roots will be readily understood by a reference to Fig. 513, where *a*, *b* represents the axis of rotation for the up and down movements with *e*, *f* as a radius ; *c*, *d* the axis of rotation along the anterior margin of the wing with *g*, *p* as a radius ; *n*, *s* the axis of rotation of the primary feathers in the direction of their length ; *m*, *r* the rotation or bending of the same feathers transversely ; the letters *h*, *i*, *j* representing the primary, and *k*, *l* the secondary feathers.

The folding and extending of the wing during the up and down strokes are seen at Fig. 514, which gives front and back views of the snipe with the feathers removed and partly dissected. This figure shows that the wing when flexed is only half the length of the wing when extended.

The manner in which the primary and secondary feathers are opened up and thrown out of gearing in flexion —how they are partly geared in semi-extension, and completely geared and banded together in extension—will be readily appreciated by a reference to Fig. 515, which represents transverse sections of the primary and secondary feathers of the wing of the magpie in the positions indicated.

The muscular arrangements, and the disposition of the primary and secondary feathers during flexion and extension in the wing of the pheasant, are given at Fig. 516. In this figure it will be observed that in the left or flexed wing, which is ready to make the up stroke, the primary and secondary feathers are separated, and present knife edges to the upper air ; whereas in the right or extended wing, which is prepared to make the down stroke,

they overlap and are banded together to prevent the escape of the nether air. It will also be seen that the roots of the primary and secondary feathers are firmly imbedded in a fringe of skin and fibro-elastic material, which, on careful examination, is found to consist of three bands of fibrous tissue running in the direction of the length of the wing, with an oblique, zigzag band extending between every two feathers. The outer band, which is the widest of the three, is further provided with two sets of strong white fibres, which wind round the root of each feather and cause it to rotate in two opposite directions during the flexion and extension of the wing. This arrangement makes it exceedingly difficult to extract the primary and secondary feathers, as all poulterers know.

The rotatory action of the two sets of white fibres is largely mechanical, and is brought into play during

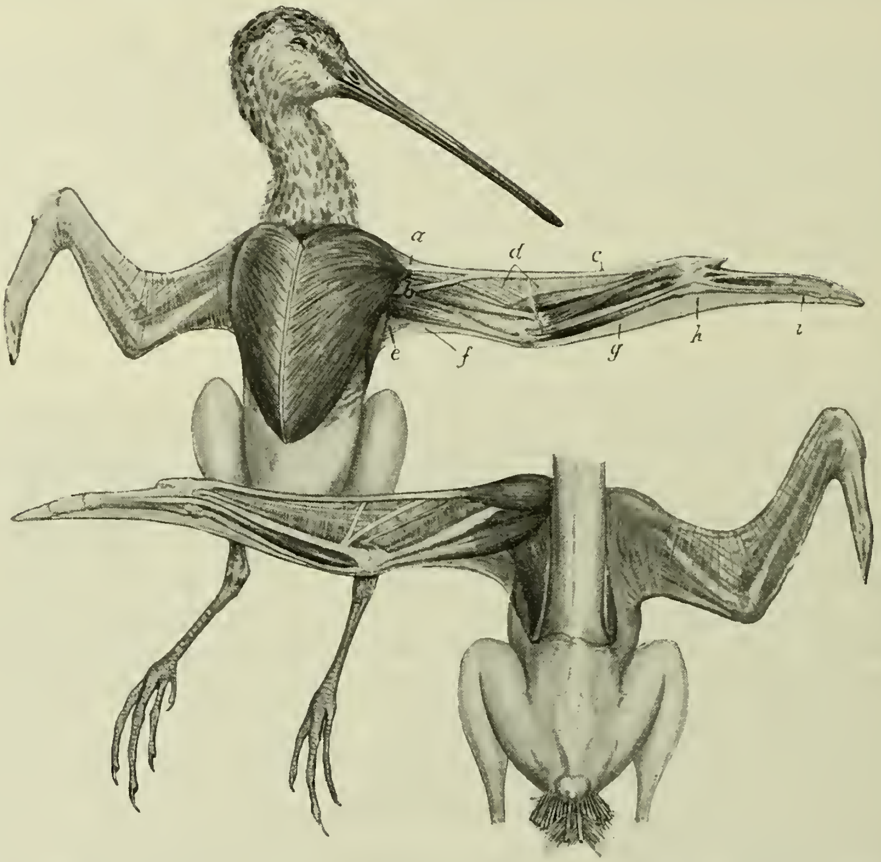


FIG. 514.—The common snipe (*Gallinago cœlestis*). *Lower figure*—dorsal view. Shows right wing flexed as in flight, with the skin, muscles, bones and elastic structures intact; also the left wing extended and partly dissected to show the muscles, bones, and elastic structures in position. The extended wing is twice as long as the flexed wing.

Upper figure.—Ventral surface of the snipe. Shows the right wing flexed and intact, and the left one extended and partly dissected to expose the muscles, bones, and elastic structures; the great pectoral muscles of the breast (depressors of the wing) are also exposed. *a*, Voluntary muscular slip terminating in a fibro-elastic band (*c*); this being in turn geared to a voluntary muscle (*b*), and to certain musculo-fibrous elastic bands (*d*). Their conjoined action is to flex the forearm on the arm; the arm being drawn towards the body by a musculo-fibrous elastic ligament (*e*, *f*). The elastic ligament (*g*, *h*) flexes the hand on the forearm, and the elastic ligament (*i*) the fingers on the hand. In the flexed condition of the right wing the skin and fibro-elastio ligaments are seen puckered and drawn together. The dorsal view of the extended left wing is given in the lower figure. (Dissected and drawn from nature by the Author, 1870.)

flexion and the up stroke, when the feathers are made to rotate in one direction, so as to separate and throw them out of gearing and let the air escape, and during extension and the down stroke, when the feathers are made to rotate in another and opposite direction, to make them overlap and close to prevent the escape of the air.

The arrangement of the muscles, musculo-fibro-elastic structures, and the distribution of the primary, secondary, and tertiary feathers of the wing, are seen to advantage in any of the large birds, such as the eagle, vulture, pelican, swan, albatross, &c.

I give careful dissections and drawings of the ventral and dorsal surfaces of the extended wing of the crested crane—a large, powerful bird—where the structural peculiarities and intricacies can be made out without difficulty.

Fig. 517 provides the necessary illustration. It deals more especially with the fibro-elastic structures and the disposition of the primary, secondary, and tertiary feathers; the muscular arrangements being taken up in detail in Plate clxxiii., p. 1248, which follows.

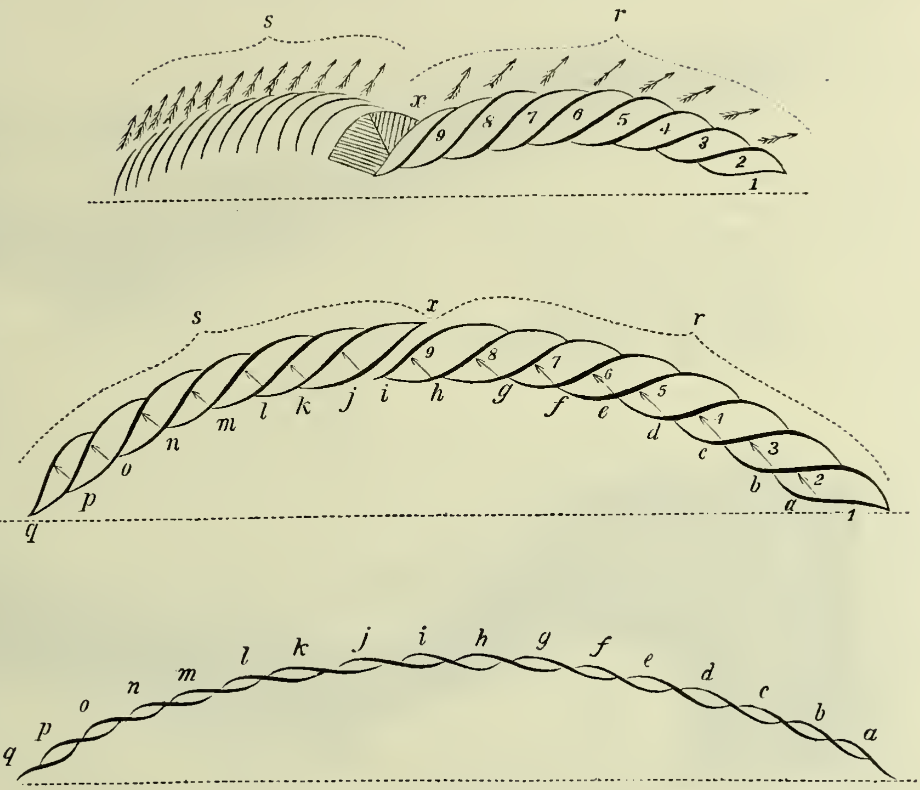


FIG. 515.

FIG. 515.—Transverse sections of the primary and secondary feathers of the wing of the magpie (*Pica rustica*) as seen in flexion, semi-flexion, and extension.

Upper figure.—The primary feathers are seen at *r* and are numbered 1 to 9; the secondary feathers occur at *s*; the space between the primaries and secondaries is shown at *x*. The arrows directed obliquely upwards indicate where the air escapes through the wing during flexion and the up stroke. Each primary feather displays a double or *f* curve very suitable for a valvular action.

Middle figure.—In this figure the wing is semi-extended and the primary and secondary feathers semi-closed. The wing is thrown into a beautiful arch, deeply concave on its under surface. The darts indicate the primary and secondary feathers in the act of closing; a process greatly facilitated by the double or *f* curve made by each individual feather. In this figure, *r* and the numbers 1 to 9 represent the primary feathers; *s*, the secondary feathers; *x*, the space between them; and the letters *a* to *q* the individual feathers.

Lower figure.—In this figure the wing is fully extended, and the primary and secondary feathers completely closed and banded together to prevent the escape of air through them during the down stroke. A more perfect arrangement for the purpose cannot be conceived. In this case, the double or *f* curve made by each feather is reversed, and the feathers plait into and support each other in the most wonderful manner. The valvular action of the feathers is complete. The individual primary and secondary feathers are lettered from *a* to *q* inclusive, and form an arch of extraordinary strength and beauty. (The sections made and drawn by the Author in 1870.)

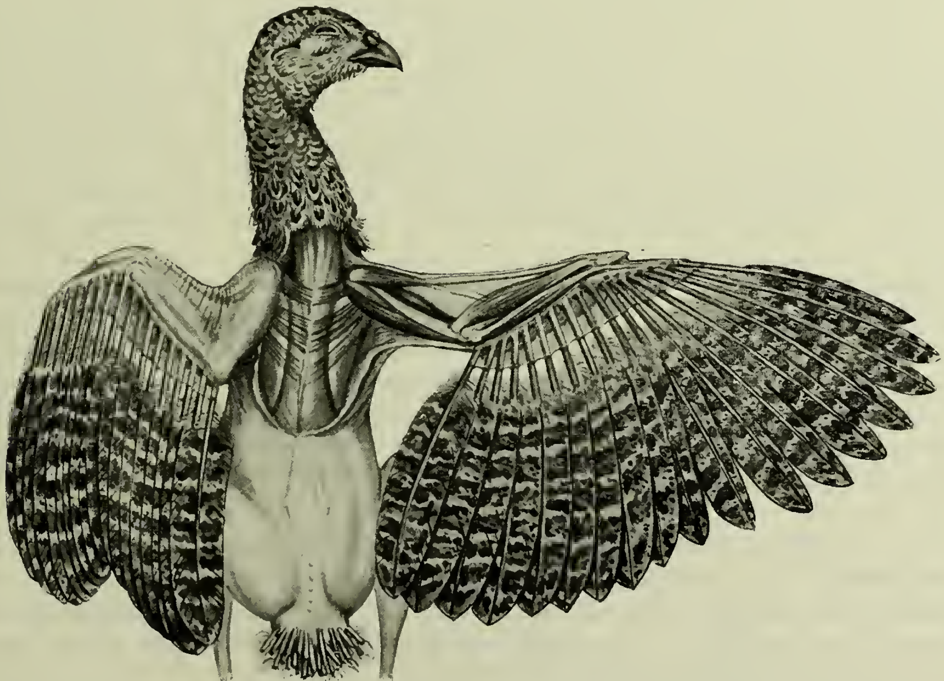


FIG. 516.—Wings of the pheasant (*Phasianus colchicus*) dissected to show the roots of the primary and secondary feathers in the flexed and extended conditions—back or dorsal view. The figure also shows the muscles of the right wing, and the muscles of the back connected with both wings. The figure will be readily understood from what has been stated above and what has gone before. (Dissected and drawn from nature by the Author.)

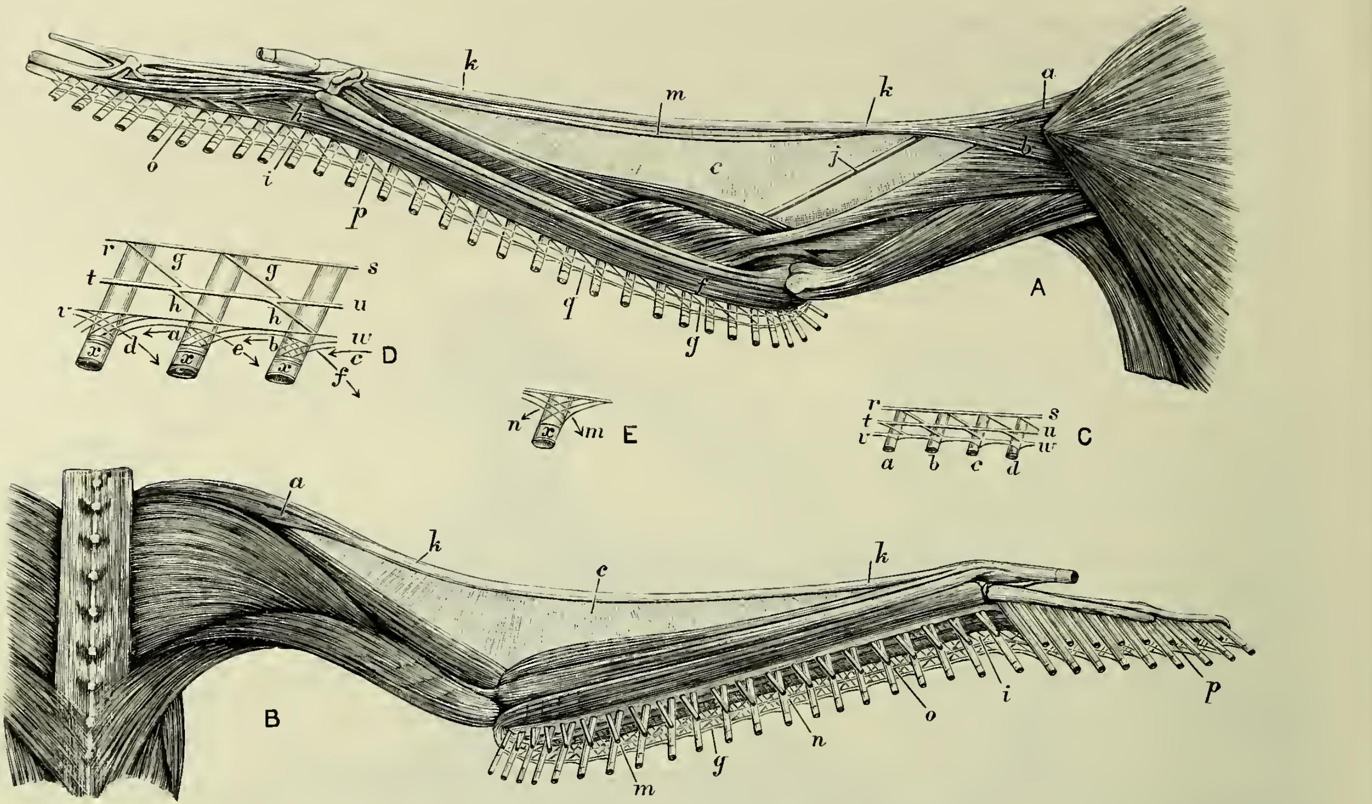


FIG. 517.—A. Dissection of the ventral aspect of the wing of the crested crane (*Balearica pavonina*). *a*, *b*, Voluntary muscular slips terminating in two strong fibro-elastic ligaments (*k*, *k*, *m*); *j*, a third fibro-elastic ligament; *c*, powerful elastic membrane. The muscular slips, fibro-elastic bands, and elastic membrane work together and in unison, and play an important part in flexing the wing prior to the up stroke by a vito-mechanical act. *f*, *g*, *h*, *i*, Musculo-fibro-elastic ligament which envelops the roots of the primary and secondary feathers. The musculo-fibro-elastic ligament forms a symmetrical network of great strength and beauty; its component parts being arranged in such a manner as to envelop the root of each individual feather. The network in question supports the feathers, and limits their peculiar valvular action. It is enlarged at C, D, E, and consists of three longitudinal bands (*r*, *s*; *t*, *u*; *v*, *w*). Between these bands two oblique bands, *g* and *h*, run. The oblique bands occur between every two feathers. The marginal longitudinal band (*v*, *w*) splits up into two processes, one of which curves round the root of each feather (*x*) in a direction from right to left (*c*, *b*, *a*), the other in a direction from left to right (*d*, *e*, *f*). These processes are also seen at *m*, *n* of E. They have the root of each feather completely under control, and their function, in conjunction with the oblique bands, is to rotate the feathers from right to left during flexion, and from left to right during extension. The longitudinal and oblique bands are so geared together that they work in harmony, all the feathers enveloped by them being made to rotate in the same direction at exactly the same instant of time. It is in virtue of the rotation of the individual primary and secondary feathers at their roots that the feathers are separated from each other during flexion, and brought into close contact during extension; and thus it is that the air is avoided during the up stroke, and seized during the down one.

B. Dissection of the dorsal aspect of the wing of the crested crane. *a*, Voluntary muscular slips terminating in two strong fibro-elastic bands (*k*, *k*), which are connected with a powerful elastic membrane (*c*). These structures are largely responsible for flexing the forearm on the arm during the up stroke, and for converting the wing into a short lever, which greatly reduces the area of the wing and the air pressure during the up stroke. *g*, *n*, Intricate musculo-fibro-elastic ligaments in which the roots of the primary and secondary feathers are imbedded, which connect and gear the feathers together, and which cause them to rotate from right to left during flexion and from left to right during extension. By this means the valvular action of the feathers is assured. When the feathers are made to rotate from right to left, as in flexion and the up stroke, they are separated, thrown out of gearing, and opened up to let the air pass between. When the feathers are made to rotate from left to right, as in extension and the down stroke, they are brought into close apposition and banded together to prevent the escape of air. The feathers during their rotatory movements work together and in unison, so that no mistake ever occurs in their valvular action either during flexion and the up stroke or during extension and the down stroke. *m*, *n*, *o*, Subsidiary root feathers placed obliquely across the roots of the secondary feathers, which act as springs for cushioning the latter; they also prevent their rising too high during the down stroke. *p*, Subsidiary root feathers wedged between the roots of the primary feathers, which prevent too much lateral play in the latter. (Dissected and drawn from nature by the Author.)

In contemplating A of Fig. 517, which shows the ventral surface of the extended wing, one is struck with the beautiful display of muscles at the root of the wing, which creep along the wing to its tip; also the powerful fibro-elastic structures which occupy its anterior margin and take a prominent part in flexing the wing; also the orderly and methodical arrangement of the primary and secondary feathers which occupy its posterior margin, and which, as explained, have an important valvular action.

At B of Fig. 517 the dorsal surface of the extended wing is seen. Here the same striking muscular, fibro-elastic arrangements are witnessed, and the same orderly and highly intricate disposition of the primary, secondary, and tertiary feathers. The primary feathers at the tip of the wing are wedged in by smaller feathers and

supported on a strong, flat, osseous platform formed by two metacarpal bones, and by the fusion of the finger-bones of the hand of the bird modified in a remarkable manner for the express purpose. The secondary feathers are also provided with smaller auxiliary feathers, which extend obliquely across their roots and act as springs to cushion them and prevent the feathers rising too high during the down stroke.

At C and D of Fig. 517, the three sets of fibrous bands which run along the roots of the primary, secondary, and tertiary feathers in the direction of the length of the wing, with a double set of fibrous bands extending obliquely between the roots of every two feathers, are strongly in evidence ; as also the two sets of white fibres which coil round the root of each feather in opposite directions, and which confer on each feather a rotatory movement in two directions, and ensure the valvular action of the wing during flexion and the up stroke, and during extension and the down stroke.

The two sets of white fibres which confer two diametrically opposite rotatory movements on the root of each primary and secondary feather are seen at E of Fig. 517.

§ 401. Muscles, Bones, Joints, Elastic Structures, &c., of the Wing of the Bird.

The bird is provided with a powerful muscular system which is very largely devoted to the propulsion of the wings in flight. Quite two-thirds of the muscles of the whole body are set apart for the discharge of this important function. The muscles of the wing are voluntary in their nature, and are put in motion and controlled by the will of the bird. The movements of the wing are never random ; they are designed and regulated, in the same sense that the movements of our own limbs in walking are. A bird has to learn to fly as a child has to learn to walk. Any dislocation of the muscles of the wing, or of its nerve supply, is fatal to flight. The wing is at once exceedingly mobile and exceedingly sensitive, and it feels about for and utilises air currents to quite an extraordinary extent.

It is this mobility and hyper-sensitiveness of the wing which in ordinary rowing flight and in sailing flight enable the bird to take advantage of every wind that blows and of every puff of wind, and to balance and steer its course with such amazing precision in the fickle, ever-changing element in which it progresses. A slight alteration in the angle made by the body or wings with the horizon, a slight tilting of the body or wings, a tremulous movement of even the primary, secondary, and tertiary feathers of the wings, suffice to give the bird the mastery of the situation.[1] It is here that the rigid, immobile, insensitive aëroplanes at present employed in aërostation fail, and become a source of danger to those who attempt to solve the problem of artificial flight by their assistance. Rigid aëroplanes do not accommodate themselves to air currents as mobile, sensitive wings do, and may suddenly, and without warning, shoot upwards, downwards, or laterally, to the dismay and discomfiture of the aëronaut.

That the wings are put in motion and their movements controlled by nerve action is proved by a very simple experiment. If the motor nerves of the wing be divided, the movements of the muscles are no longer co-ordinated, and the muscles cease to work harmoniously. The movements of the wing under these circumstances become inexact and sprawling, and though frequently violent, are wholly ineffective for the purposes of flight.

When the art of flight has been once acquired, the up and down strokes of the wing are delivered with the greatest precision and regularity. The wing movements ultimately become rhythmic in character and more or less automatic.

Considerable misapprehension exists as to the manner in which the wing of the bird is propelled during the up and down strokes. Some, following the lead of Chabrier, who advocates a mechanical action of the wing in the insect, incline to the belief that the wing is depressed by voluntary muscular action, but that it is elevated by the reaction of the air (compressed by the descent of the wing) on its under surface, which forces it mechanically upwards. This view is negatived by the presence in the bird of an independent and separate set of muscles for elevating the wing ; and especially by the fact that when the wing is flexed, its area is reduced by half, and its primary and secondary feathers separated and opened up to let the air escape.

The muscular and other arrangements of the wing of the bird are seen to advantage in the pigeon, a bird of powerful flight and easily available for purposes of reference. I give original dissections and drawings of the ventral and dorsal aspects of the bird, and also a view of the bones of the wing in which the extraordinary modifications of the wrist, and especially of the hand which supports the roots of the primary or rowing feathers, are given. These modifications consist of a reduction of the carpal bones of the wrist, of a reduction of the metacarpal bones to two, and of the digits to three. Nor is this all ; the first digit or thumb, which forms the alula or false

[1] At the Bass Rock, Firth of Forth, Scotland, at the breeding season, the gannets are exceedingly tame, and fly about within a few yards of one's head. In such circumstances I have actually seen the changes referred to above occurring in the body, wings, and feathers. The tameness of the gannets when sitting on eggs is phenomenal, and I have again and again poked them off their nests with my stick. On such occasions, they did not go more than a few feet from their eggs, and returned to them the moment I left.

PLATE CLXXIII

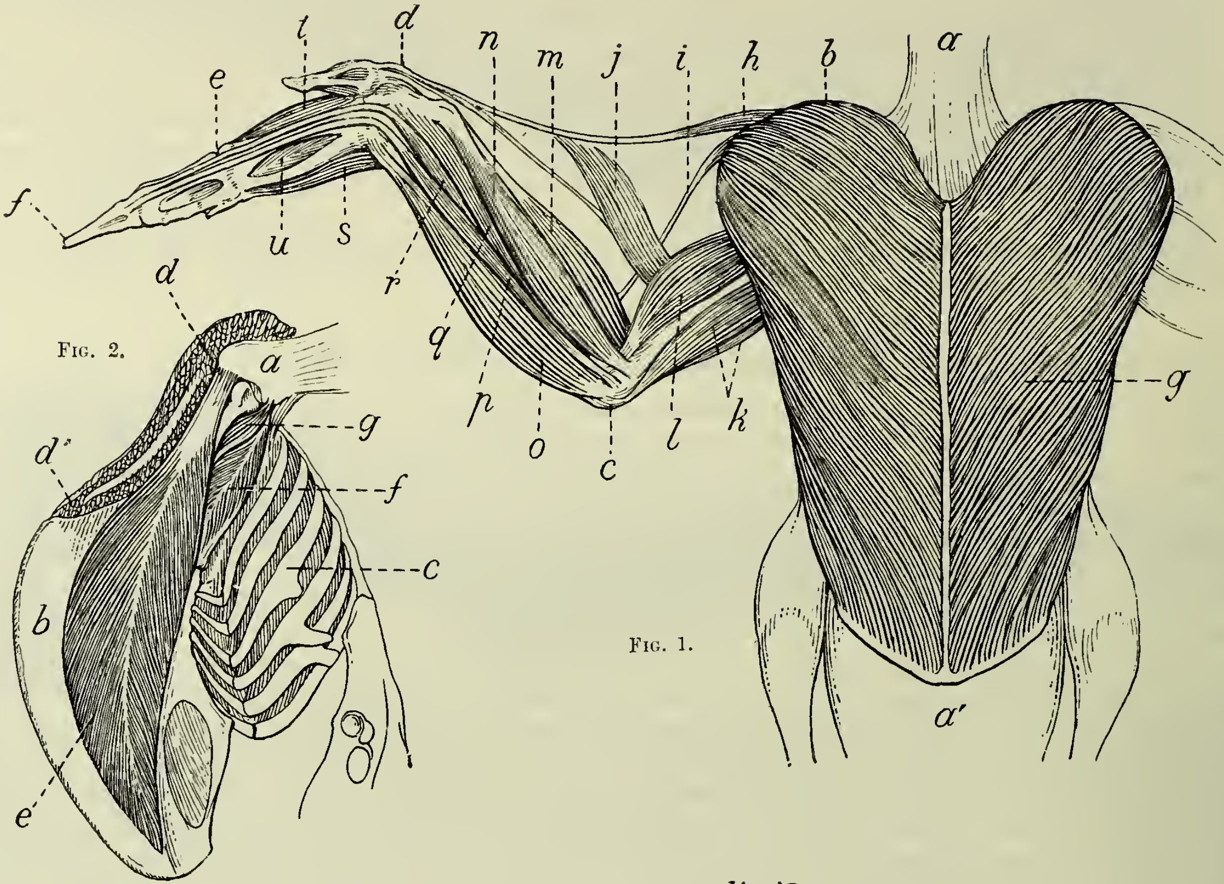


Fig. 1.

Fig. 2.

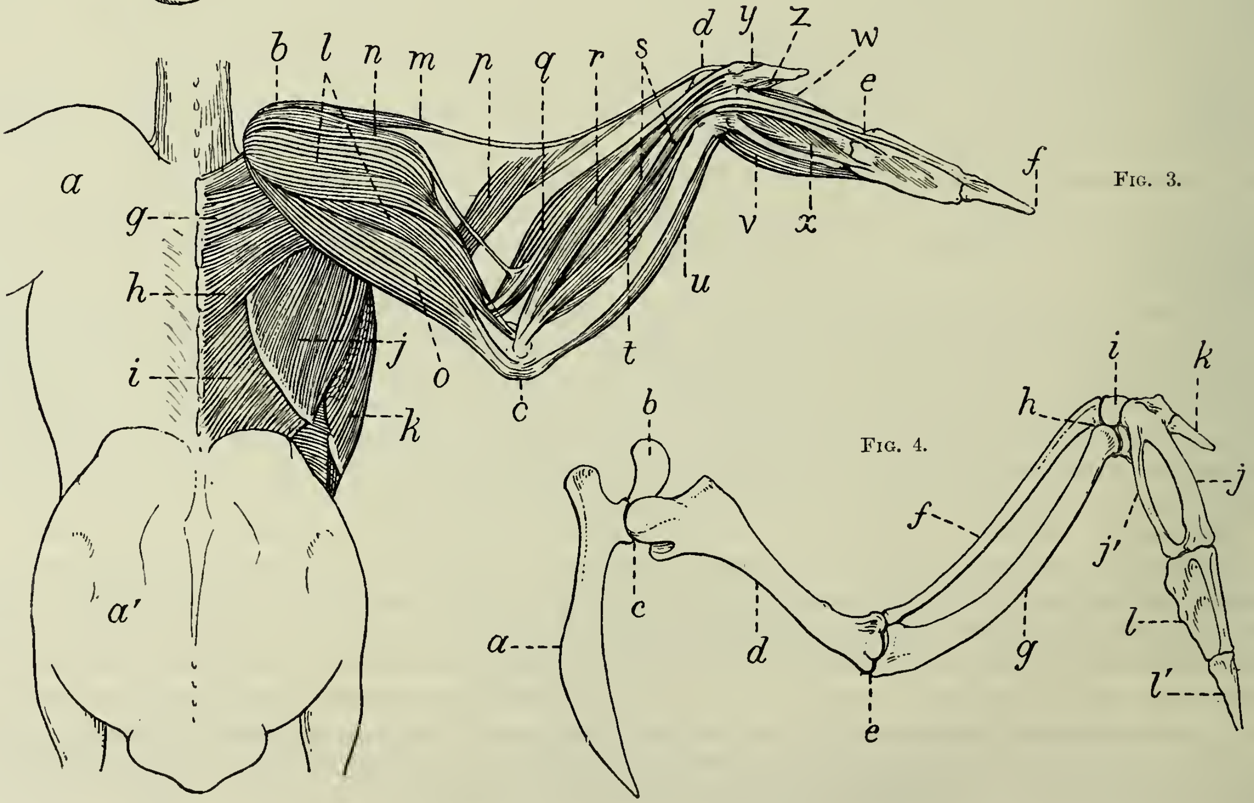


Fig. 3.

Fig. 4.

wing, is displaced and occurs near the wrist; while the two metacarpal bones and the remaining two digits are flattened and soldered together, and so greatly elongated that when taken together they measure as much as the cubitus or forearm (Plate clxxiii., Fig. 4).

It will be observed that the wrist and hand of the pigeon are altered and modified almost beyond recognition; the object being to confer amplification and strength on these parts, which afford support to the primary or rowing feathers on which flight chiefly depends. This modification of the wrist and hand of the bird for a special purpose furnishes a very striking example of design. It is not due to evolution, which carries with it the idea of an advance from a lower to a higher level, but to development in a particular direction, and to arrest of development and suppression of parts in another and opposite direction, which cannot be explained apart from original endowment and a special provision of means to ends.

The hand of the bird is, in several respects, even more wonderful than the foot of the horse. Both are specially modified, specially endowed structures, and when regard is had to the particular functions to be discharged by them respectively, they must stand forth as crowning examples of original creations, and the outcome of intelligence alike from the physical, physiological, and teleological points of view (*vide* Plate clxxiii., Fig. 4).

PLATE CLXXIII

Plate clxxiii.—Shows anterior and posterior views of the muscles, ligaments, elastic structures, &c., connected with flight, in the wing of the pigeon: also the bones, joints, and greatly modified wrist and hand of the bird. (Drawn by C. Berjeau for the present work from original dissections by the Author.)

Fig. 1.—Ventral aspect of the pigeon (*Columba livia*), with the chest and wing muscles dissected. *a*, *a'*, The body; *b*, *c*, the humerus or arm-bone; *c*, *d*, the radius and ulna (forearm or cubitus); *d*, *e*, *f*, the hand; *g*, the pectoralis major or great depressor muscle of the wing; *h*, tensor plicæ alæ (tensor patagii longus) which stretches the fibro-elastic ligament; *i*, tensor patagii brevis which assists in stretching the fibro-elastic ligaments; *j*, retractor plicæ alæ which draws back the fibro-elastic ligaments during the flexion of the wing; *k*, extensor of the forearm or cubitus, also known as the triceps; *l*, the biceps muscle which flexes the forearm on the arm; *m*, the extensor metacarpi radialis longior, also known as the supinator radii longus; *n*, the pronator radii teres; *o*, flexor carpi ulnaris; *p*, palmaris longus; *q*, flexor carpi radialis; *r*, flexor digitorum; *s*, abductor digiti; *t*, adductor digiti; *u*, supinator or extensor digiti (interosseus palmaris).

Fig. 2.—Lateral view of the thorax of the pigeon. *a*, The head of the humerus or arm-bone; *b*, the keel of the breast-bone or sternum; *c*, the ribs with flat bony processes for gearing them together and supporting them under strain—the interosseus muscles are seen between the ribs; *d*, *d'*, the pectoralis major, the great depressor of the wing, cut across; *e*, *f*, the pectoralis medius and pectoralis minor; *g*, the clavicularis muscle.

Fig. 3.—Muscles of the dorsal surface of the wing of the pigeon. *a*, The body; *b*, *c*, humerus or arm-bone; *c*, *d*, cubitus or forearm; *d*, *e*, *f*, the hand; *g*, the latissimus dorsi (its anterior portion); *h*, the latissimus dorsi (its posterior portion); *i*, the trapezius; *j*, the infra spinatus; *k*, the pectoralis major; *l*, the deltoides or elevators of the wing; *m*, tensor plicæ alæ (tensor patagii longus); *n*, tensor patagii brevis—these two muscles stretch the fibro-elastic ligaments; *o*, the extensor cubiti or triceps, the muscle which extends the forearm; *p*, the retractor plicæ alæ, the muscle which draws back the fibro-elastic ligaments in flexion; *q*, the flexor cubiti or biceps which folds the forearm on the arm; *r*, the extensor carpi radialis brevis; *s*, the extensor and flexor digitorum; *t*, the extensor carpi ulnaris; *u*, the flexor carpi ulnaris; *v*, the abductor digiti; *w*, the adductor digiti; *x*, the supinator or extensor digiti (interosseus palmaris); *y*, the abductor digiti (extensor proprius pollicis); *z*, the adductor primi digiti.

Fig. 4.—The bones of the wing of the pigeon. *a*, The scapula; *b*, the tip of the coracoid bone; *c*, the shoulder-joint, universal in its nature; *d*, the humerus or arm-bone; *e*, the elbow-joint—a spiral hinge joint; *f*, *g*, the radius and ulna (the cubitus or forearm); *h*, the wrist-joint; *i*, two carpal bones; *j*, *j'*, the second and third metacarpal bones joined above and below by osseous union; *k*, the pollex or thumb (first finger); *l*, *l'*, the phalanges of the second and third two fingers fused and soldered together. The second and third metacarpal bones, and the corresponding second and third phalanges or finger-bones are flattened and more or less completely fused to afford a strong, flat, osseous support for the roots of the primary feathers, which are chiefly engaged in flight.

§ 402. Dimensions and Weights of Important Parts of the Pigeon (*Columba livia*).

It may interest the reader if, at this stage, I supply a carefully prepared table of the measurements and weights of the more outstanding parts of this much cherished and highly popular bird. I have prepared and append such a table, compiled from data furnished by a fully grown, finely plumaged, fresh specimen.

The table enables us to arrive at certain important conclusions having a direct bearing on the interesting subject of flight.

The pigeon is a powerful flyer, provided with moderate sized, well formed, strong wings. It also possesses a highly developed muscular system.

The expanse of the wings, measured across the back, is $28\frac{1}{2}$ inches; the wings, where widest, being $5\frac{3}{4}$ inches. The muscles of the wings are large and powerful, and they (or their tendons) extend quite to the tips of the wings, thus demonstrating that all parts of the wings are thoroughly under control.

The weight of the body is 17 ozs., while that of the great pectoral or chest muscles which depress the wings during the down strokes is $4\frac{3}{4}$ ozs. This is considerably more than a quarter of the weight of the entire body,

and goes to show the tremendous energy with which the wings are driven during the down strokes. In order to sustain the great downward thrust of the wings, the skeleton of the pigeon, and other flying birds, is provided with two strong, vertical, bony columns (coracoid bones), extending between the upper portions of the great keel-shaped sternum and the clavicles (furcula). The coracoid bones, clavicles, and scapulæ form tripods of support for the heads of the humeri, and enter into the composition of the ball-and-socket shoulder-joints.

The muscles, tendons, and elastic structure of the wings, including the muscles of the shoulders (elevators of the wings), scapulæ, and those connecting the wings with the body and with the spines of the dorsal vertebræ, weigh $1\frac{3}{4}$ ozs. The muscles connected with flight, therefore, reach the grand total of $6\frac{1}{2}$ ozs., which is considerably more than a third of the whole weight of the bird. The power of the wings is thus assured. The muscles and tendons of the legs, including those which connect the legs with the body and back, only weigh $\frac{3}{4}$ of an oz., showing that the leg muscles are sacrificed to the wing muscles and the exigencies of flight.

The entire muscles of the pigeon may be estimated at 8 ozs., and of this muscular aggregate, the wings and the wing movements appropriate no less than $6\frac{1}{2}$ ozs. Here, surely, is an outstanding example of "means to ends" and of design and of prescient intelligence. Not only the muscles and soft parts of the wings, but, as has been shown, the osseous or hard parts of the wings, are much modified and severely subordinated to the inexorable demands of flight. Such results cannot be attained by any process of "evolution" or "natural selection," however long continued, and the wings of birds must be regarded as original creations so far as their muscles, bones, nerves, elastic structures, and primary, secondary, and tertiary feathers are concerned. No kind of environment could possibly produce the startling modifications witnessed in the wings adapted for aërial flight, and no amount of wishing and willing on the part of animals desirous of flying could ever bring about such unlooked-for and extraordinary changes. Wings are nothing, if they are not original, specially endowed structures. Their presence can only be explained by regarding them as integral fundamental parts of the animals possessing them. They are not makeshift organs, but *bonâ fide* original organs, created to discharge a most difficult and indispensable function.

Professor Sir E. Ray Lankester, in his recent interesting work, "Extinct Animals" (1905), expresses a contrary opinion, which, however, he admits is beset with difficulties, and only partially explains the facts. Speaking of the wings of pterodactyls and bats, he refers to those of flying fishes and insects in the following words: "There are other two kinds of flying animals, namely, the flying fishes (which do not fly far), and the six-legged insects or flies, bees, and beetles. They have all independently acquired the habit of flying, and have had certain parts of their bodies changed into wings. The process of change must have been gradual, and have taken an enormous lapse of time to bring it about in each kind. . . . Probably the wings of birds and of insects were both derived from fin-like organs which were used to swim with before they were used in the air. But the origin of the wing of the pterodactyls, and independently that of the wing of the bats, does not seem to have been of this nature, and is one of the many very puzzling matters which further discoveries may one day enable us to understand."

In connection with the above quotation I have to observe that there is no proof whatever that flying fishes, insects, and birds "have all independently acquired the habit of flying, and have had certain parts of their bodies changed into wings." No amount of repetition of wing movements could ever result in flight in the absence of fully developed wing structures, and no animal has the power of developing travelling organs, especially wings, at will. That power could only be exerted by the original Maker of the animal, while it was in process of formation. Moreover, the wings of pterodactyls and bats do not essentially differ from those of insects and birds. They present no difficulties which do not equally exist in the wings of insects and birds. As a matter of fact, and as I have already explained, all wings are formed on a common model, and cannot be dissociated. The same plan of construction is traceable in all, and they are, in every case, to be regarded as original integral parts of the animals possessing them.

MEASUREMENTS OF PARTS OF PIGEON (*Columba livia*)

Length of body from tip of beak to tip of tail	17	ins.
Girth of body at widest part of chest	10	,,
Length of beak, head, and neck	6	,,
Length of body	$5\frac{1}{2}$	,,
Length of tail	$5\frac{1}{2}$	,,
Expanse of wings from tip to tip, measured across back	$28\frac{1}{2}$	,,
Length of wing from root to tip	13	,,
Breadth of wing where widest	$5\frac{1}{2}$	,,
Breadth of primary feathers where widest	$4\frac{1}{2}$	,,
Breadth of secondaries, where widest	$5\frac{3}{4}$	,,
Width of secondaries nearest to body	5	,,

WEIGHTS OF PARTS OF PIGEON (*Columba livia*)

Weight of entire body	17	ozs.
Weight of integument and feathers	$2\frac{1}{2}$	,,
Weight of muscles of chest—pectorals—depressors of the wings	$4\frac{3}{4}$	,,
Weight of muscles, tendons, and elastic structures of wings, including muscles of shoulders (elevators of the wings), scapulæ, and the muscles connecting the wings with the spines of the dorsal vertebræ	$1\frac{3}{4}$	,,
Weight of muscles and tendons of legs, including the muscles which connect the legs with the body and back	$\frac{3}{4}$	,,
Weight of viscera	$3\frac{1}{4}$	,,
Weight of skeleton, including muscles of head, neck, abdomen, and tail	4	,,

§ 403. Consideration of the Forces which propel the Wings of Birds and Bats.

The muscular system of birds has been already fully described, and I need only repeat in this connection that there are muscles which by their action are capable of elevating and depressing the wings, and of causing them to move in a forward and backward direction, and obliquely. They can also extend or straighten and bend or flex the wings, and cause them to rotate in the direction of their length during the down and up strokes. The muscles principally concerned in the elevation of the wings are the smaller pectoral or breast muscles (*pectoralis minor*); those chiefly engaged in depressing the wings are the larger pectorals (*pectoralis major*). The pectoral muscles correspond to the fleshy mass found on the breast-bone or sternum, which in flying birds is boat-shaped, and furnished with a keel. These muscles are sometimes so powerful and heavy that they outweigh all the other muscles of the body. The power of the bird is thus concentrated for the purpose of moving the wings and conferring steadiness upon the volant mass. In birds of strong flight the keel is very large, in order to afford ample attachments for the muscles delegated to move the wings. In birds which cannot fly, as the members of the ostrich family, the breast-bone or sternum has no keel.

The remarks made regarding the muscles of birds apply with very slight modifications to the muscles of bats. The muscles of bats and birds, particularly those of the wings, are geared to, and act in concert with, elastic ligaments or membranes, to be described presently.

§ 404. Lax Condition of the Shoulder-joint in Birds, Bats, &c.

The great laxity of the shoulder-joint in birds and bats readily admits of their bodies falling downwards and forwards during the up stroke. This joint, as has been already stated, admits of movement in every direction, so that the body of the bat or bird is like a compass set upon gimbals—that is, it swings and oscillates, and is equally balanced, whatever the position of the wings. The movements of the shoulder-joint in the bird, bat, and insect are restrained within certain limits by a system of check ligaments and prominences; but in each case the range of motion is very great, the wings being permitted to swing forwards, backwards, upwards, downwards, or at any degree of obliquity. They are also permitted to rotate along their anterior margin, or to twist in the direction of their length to the extent of nearly a quarter of a turn. This great freedom of movement at the shoulder-joint enables the insect, bat, and bird to rotate and balance upon two centres—the one running in the direction of the length of the body, the other at right angles or across the body, in the direction of the length of the wings.

In the bird the head of the humerus is convex and somewhat oval (not round), the long axis of the oval being directed from above downwards—that is, from the dorsal towards the ventral aspect of the bird. The humerus can, therefore, *glide up and down* in the *facettes* occurring on the articular ends of the coracoid and scapular bones with great facility, much in the same way that the head of the radius glides upon the distal end of the humerus. But the humerus has another motion; it moves *like a hinge from before backwards, and vice versâ*. The axis of the latter movement is almost at right angles to that of the former. As, however, the shoulder-joint is connected by long ligaments to the body, and can be drawn away from it to an appreciable extent, it follows that *a third and twisting movement can be performed*, the twisting admitting of rotation to something like a quarter of a turn. In raising and extending the wing preparatory to the downward stroke two opposite movements are required, namely, one from before backwards, and another from below upwards. As, however, the axes of these movements are at nearly right angles to each other, a spiral or twisting movement is necessary to run the one into the other —to turn the corner, in fact.

From what has been stated it will be evident that the movements of the wing, particularly at the root, are remarkably free, and very varied. A directing and restraining, as well as a propelling force, is therefore necessary.

The guiding force is to be found in the voluntary muscles which connect the wing with the body in the insect, and which in the bat and bird, in addition to connecting the wing with the body, extend along the pinion even to its tip. It is also to be found in the musculo-elastic and other ligaments, seen to advantage in the bird.

§ 405. The Wing Flexed and partly Elevated by the Action of Elastic Ligaments—the Nature and Position of such Ligaments in the Pheasant, Snipe, Crested Crane, Swan, &c.

When the wing is drawn away from the body of the bird by the hand, the posterior margin of the pinion formed by the primary, secondary, and tertiary feathers rolls down to make a variety of inclined surfaces with the horizon. When, however, the hand is withdrawn, even in the dead bird, the wing instantly folds up; and in doing so reduces the amount of inclination in the several surfaces referred to. The wing is folded by the action of certain elastic ligaments, which are put upon the stretch in extension, and which recover their original form

and position in flexion. This simple experiment shows that the various inclined surfaces requisite for flight are produced by the mere acts of extension and flexion in the dead bird. It is not, however, to be inferred from this circumstance that flight can be produced without voluntary movements any more than ordinary walking. The muscles, bones, ligaments, feathers, &c., are so adjusted with reference to each other that if the wing be moved at all, it must move in the proper direction—an arrangement which enables the bird to fly without thinking, just as we can walk without thinking. There cannot, however, be a doubt that the bird has the power of controlling its wings both during the down and up strokes ; for how otherwise could it steer and direct its course with such precision in obtaining its food ? how fix its wings on a level with or above its body for skimming purposes ? how fly in a curve ? how fly with, against, or across air currents ? how project itself from a rock directly into space ? or how elevate itself from a level surface by the laboured action of its wings ?

The wing of the bird is elevated to a certain extent in flight by the reaction of the air upon its under surface ; but it is also elevated by muscular action—by the contraction of the elastic ligaments, and by the body falling downwards and forwards in a curve.

That muscular action is necessary is proved by the fact that the pinion is supplied with distinct elevator muscles.[1] It is further proved by this, that the bird can, and always does, elevate its wings prior to flight, quite independently of the air. When the bird is fairly launched in space the elevator muscles are assisted by the tendency which the body has to fall downwards and forwards ; by the reaction of the air ; and by the contraction of the elastic ligaments. The air and the elastic ligaments contribute to the elevation of the wing, but both are obviously under control—they, in fact, form links in a chain of motion which at once begins and terminates in the muscular system.

That the elastic ligaments are subsidiary and to a certain extent under the control of the muscular system in the same sense that the air is, is evident from the fact that voluntary muscular fibres run into the ligaments in question at various points. The ligaments and muscular fibres act in conjunction, and fold or flex the forearm on the arm. There are others which flex the hand upon the forearm. Others draw the wing towards the body.

The elastic ligaments, while occupying a similar position in the wings of all birds, are variously constructed and variously combined with voluntary muscles in the several species.

§ 406. The Elastic Ligaments more Highly Differentiated in Wings which Vibrate Rapidly.

The elastic ligaments of the swan are more complicated and more liberally supplied with voluntary muscle than those of the crane, and this is no doubt owing to the fact that the wings of the swan are driven at a much higher speed than those of the crane. In the snipe the wings are made to vibrate very much more rapidly than in the swan, and, as a consequence, we find that the fibro-elastic bands are not only greatly increased, but they are also geared to a much greater number of voluntary muscles, all which seems to prove that the musculo-elastic apparatus employed for recovering or flexing the wing towards the end of the down stroke becomes more and more highly differentiated in proportion to the rapidity with which the wing is moved.[2] The reason for this is obvious. If the wing is to be worked at a higher speed, it must, as a consequence, be more rapidly flexed and extended. The rapidity with which the wing of the bird is extended and flexed is in some instances exceedingly great ; so great, in fact, that it escapes the eye of the ordinary observer. The speed with which the wing darts in and out in flexion and extension would be quite inexplicable, but for a knowledge of the fact that the different portions of the pinion form angles with each other, these angles being instantly increased or diminished by the slightest quiver of the muscular and fibro-elastic systems. If we take into account the fact that the wing of the bird is recovered or flexed by the combined action of voluntary muscles and elastic ligaments ; that it is elevated to a considerable extent by voluntary muscular effort ; and that it is extended and depressed entirely by muscular exertion, we shall have difficulty in avoiding the conclusion that the wing is thoroughly under the control of the muscular system, not only in flexion and extension, but also throughout the entire down and up strokes.

An arrangement in every respect analogous to that described in the bird is found in the wing of the bat, the covering or web of the wing in this instance forming the principal elastic ligament.

[1] Mr. Macgillivray and C. J. L. Krarup, a Danish author, state that the wing is elevated by a vital force, viz. by the contraction of the *pectoralis minor*. This muscle, according to Krarup, acts with one-eighth the intensity of the *pectoralis major* (the depressor of the wing). He bases his statement upon the fact that in the pigeon the pectoralis minor or elevator of the wing weighs one-eighth of an ounce, whereas the pectoralis major or depressor of the wing weighs seven-eighths of an ounce. It ought, however, to be borne in mind that the volume of a muscle does not necessarily determine the precise influence exerted by its action ; for the tendon of the muscle may be made to act upon a long lever, and under favourable conditions for developing its powers, while that of another muscle may be made to act upon a short lever, and, consequently, under unfavourable conditions. ("On the Flight of Birds," p. 30. Copenhagen, 1869.)

[2] A careful account of the musculo-elastic structures occurring in the wing of the pigeon is given by Mr. Macgillivray in his "History of British Birds," pp. 37, 38.

§ 407. Power of the Wing—to what owing.

The shape and power of the pinion depend upon one of three circumstances—to wit, the length of the humerus,[1] the length of the cubitus or forearm, and the length of the primary feathers. In the swallow the humerus, and in the humming-bird the cubitus, is very short, the primaries being very long; whereas in the albatross the humerus or arm-bone is long and the primaries short. When one of these conditions is fulfilled, the pinion is usually greatly elongated and scythe-like—an arrangement which enables the bird to keep on the wing for immense periods with comparatively little exertion, and to wheel, turn, and glide about with exceeding ease and grace. When the wing is truncated and rounded, a form of pinion usually associated with a heavy body, as in the grouse, quail, diver, and grebe, the muscular exertion required, and the rapidity with which the wing moves, are very great; those birds, from a want of facility in turning, flying either in a straight line or making large curves. They, moreover, rise with difficulty, and alight clumsily and somewhat suddenly. Their flight, however, is perfect while it lasts.

The goose, duck, pigeon, and crow are intermediate both as regards the form of the wing and the rapidity with which it is moved.

The heron and humming-bird furnish extreme examples in another direction—the heron having a large wing with a leisurely movement, the humming-bird a comparatively large wing with a greatly accelerated one.

But I need not multiply examples; suffice it to say that flight may be attained within certain limits by every size and form of wing, if the number of its oscillations be increased in proportion to the weight to be raised.

§ 408. The Skeleton or Osseous System of the Bird (Golden Eagle).

In contemplating the skeleton of the bird one is at once struck with the comparatively small size of the body, with the enormous development of the anterior extremities or wings as compared with the anterior extremities of all other animals, as also with the dwarfed dimensions of the posterior extremities or legs of the bird itself. Unless in the birds of prey, where powerful legs, feet, and talons are required for seizing, rending, and, in certain cases, carrying off the quarry, the wings are greatly in excess of the legs. Even in the golden eagle—our typical bird of prey—the wings exceed the legs by more than one-third in length, and the corresponding bones of the wings are much thicker and stronger than those of the legs. All this is necessary to increase the great expanse of wing required for the purposes of flight.

Of course, wings vary in size according to the kind of work to be performed by them. Thus in the auks, penguins, and guillemots, which fly under water, the wings are reduced to a minimum and are comparatively small. In the divers, loons, and grebes they are also small. In the heavy-bodied, short-winged birds, such as the turkey, pheasant, grouse, and partridge, they are larger, but still small compared with the size of the body. It is in the sea-going birds, such as the gull, tern, gannet, frigate bird, pelican, and albatross, and in the larger land birds, such as the herons, eagles, and vultures, that they attain their fullest development. Wings intermediate in size are found in the duck, goose, pigeon, owl, magpie, crow, woodcock, snipe, landrail, and plover.

To make the large, powerful wing bones as light and as strong as possible, they are, as a rule, composed of hollow cylinders filled with air instead of marrow. This is one of the refinements of construction which the Master-mechanician has adopted in carrying out the high purpose of flight.

While a very large proportion of birds are provided with hollow bones and air sacs, it is well to bear in mind that flight is not dependent on either the one or the other. The bats have marrow in their bones and no air sacs. The same is true of the swifts and many excellent flying birds.

According to Dr. Crisp, the swallow, martin, and many birds of passage have no air in their bones.

It is only necessary to allude, in a passing way, to the wingless birds, such as the dodo, apteryx, moa, ostrich, emu, and cassowary. They have no part in flight. It will suffice to say, that there is no reason to believe that the wingless running birds ever had wings, or that the aborted wings they possess are degenerations. The rudimentary wings indicate a general structural plan and arrest of development at a given point and for a specific purpose. The wingless birds have the same warrant for their existence as the flying birds. Both afford examples of design and of growth and modification in particular directions with a view to secure certain results in the great scheme of nature. The presence, or absence, or partial development of a structure depend wholly on the end to be achieved. Structures are in every instance means to ends, and if they are not required they are not

[1] "The humerus varies extremely in length, being very short in the swallow, of moderate length in the gallinaceous birds, longer in the crows, very long in the gannets, and unusually elongated in the albatross. In the golden eagle it is also seen to be of great length." (Macgillivray's "British Birds," vol. i., p. 30.)

developed at all, or only partially developed. The wingless birds cannot be regarded as evolutions, as they do not represent progress and advance, but arrested developments and retrogressions, in which evolution can take no part.

There is no proof that fully grown, useful flying wings deteriorate from non-use. The domestic fowl has

FIG. 518.—The skeleton of the golden eagle, drawn according to scale and from nature. Mark the great size of the wings as compared with the legs and body. The bones and joints of the wing are all more or less spiral in their nature. *a*, The shoulder-joint—this joint, which unites the wing to the body, consists of a loose, ball-and-socket, spiral arrangement which confers universality of movement on the wing; *b*, the humerus or arm-bone; *c*, the elbow-joint; *d*, *e*, the ulna and radius (the cubitus or forearm of the wing); *f*, the wrist-joint; *g*, the thumb or first finger of the hand of the bird—this forms the alula or false wing; *h*, *i*, second and third metacarpal bones of the hand soldered together at top and bottom by osseous union; *j*, metacarpo-phalangeal joint; *k*, *l*, two or more phalanges or fingers of hand flattened and fused together; *m*, phalangeal or finger-joint; *n*, terminal digit. The bones and joints of the leg, like those of the wing, are also spiral in character. *o*, The hip-joint (universal in its nature) which connects the leg to the body; *p*, the femur or thigh-bone; *q*, the knee-joint; *r*, the tibia and fibula or leg-bones; *s*, the ankle-joint; *t*, two metatarsal bones fused and blended into one bone; *u*, metatarso-phalangeal joint; *v*, the digits and talons or claws of the foot.

flown rarely, and only intermittently, during the last six or seven thousand years, yet its wings are fully developed, and equal to flight if necessary. A distinction is to be drawn between a useful organ perfectly formed at the outset as an integral part of an organism, and its possible deterioration from disuse; and between an imperfect, useless organ which has no function assigned to it and could not be called into being by externalities to fulfil a want which is not felt, or meet a set of conditions which do not exist. The wingless birds, primarily, are *runners* and

not flyers, and, as a consequence, the legs are greatly developed at the expense of the wings. The wingless condition is an adaptation to a purely terrestrial existence, but not a purposeless adaptation. The end justifies the means, and explains the situation. Large, fully developed flying wings would be as inconvenient to the running birds as large anterior and posterior extremities would be to the flying birds, or to the whales, porpoises, and sea-mammals generally. The non-possession of wings by running birds confines the movements of such birds to the earth, in the same way that the non-possession of large arms and legs and the presence of a powerful swimming tail confine the movements of the sea mammals to the water. These modifications and adaptations bristle with design. They are not the outcome of chance, but of the highest intelligence working in certain grooves to achieve certain results which are predetermined and fully understood from the first.

While nature cannot afford to wait indefinitely for the development of organs which are superfluous or useless until they are fully developed, neither will she unreservedly pledge herself to keep up useful organs if they are not called upon to discharge their appropriate functions. Some parasites lose their legs when they adopt the parasitic habit; the fishes which live in dark caves ultimately lose the use of their eyes. It is the glory of the universe that everything which exists has a function to perform; the cosmos consisting of an interminable system of actions and reactions all working together for good.

It is not necessary to deal with the skeleton of the bird as a whole. I will, therefore, confine my observations mainly to the wings and legs. It should, however, be stated that the bodies of flying animals are much inferior in size to those of other animals; their anterior extremities or wings being very greatly in excess. They have also large scapulæ, coracoid bones, and clavicles (furcula) to support the greatly developed humeri or arm-bones and an immense breast-bone with a keel to give attachment to the powerful pectoral muscles which depress the wings during the down stroke. The ribs are also provided with transverse, bony processes which band these structures together and ensure mutual support against sudden or unusual strain.

These several points, as well as the relative sizes of the bones of the wings, legs, and body, are illustrated at Fig. 518, an accurate representation of the skeleton of the golden eagle which I have had specially drawn from nature by C. Berjeau for the present work.

The eagle (acknowledged king of birds) flies by the rowing movement of its wings, and also by sailing, skimming, and gyratory movements. I have had frequent opportunities of studying the flight of this magnificent bird in the Highlands of Scotland. It resembles that of the large hawks in general. When hunting, the eagle flies for several hundred yards by the flapping of its large, powerful wings, after which it glides or sails for a longer or shorter distance, when the flapping is renewed. When not hunting, the bird seeks the upper ether by alternate flapping and skimming movements in huge upward spirals until it appears a mere speck in the vast dome of heaven.

§ 409. The Bones of the Wing of the Bird—their Articular Surfaces, Movements, &c.

The humerus, or arm-bone of the wing, is supported by three of the trunk-bones, namely, the scapula or shoulder-blade, the clavicle or collar-bone, also called the *furculum*, and the coracoid bone—these three converging to form a *point d'appui*, or centre of support for the head of the humerus, which is received in *facettes* or depressions situated on the scapula and coracoid.[1] In order that the wing may have an almost unlimited range of motion, it is articulated to the trunk by a somewhat lax universal joint, which permits vertical, horizontal, and intermediate movements.[2] The long axis of the joint is directed vertically; the joint itself somewhat backwards. It is otherwise with the elbow-joint, which is turned forwards, and has its long axis directed horizontally, from the fact that the humerus is twisted upon itself to the extent of nearly a quarter of a turn. The elbow-joint is decidedly spiral in its nature, its long axis intersecting that of the shoulder-joint at nearly right angles. The humerus articulates at the elbow with two bones, the radius and the ulna, the former of which is pushed from the humerus, while the other is drawn towards it during extension; the reverse occurring during flexion. Both bones, moreover, while those movements are taking place, revolve to a greater or less extent upon their own axes. The bones of the forearm articulate at the wrist with the carpal bones, which being spirally arranged, and placed obliquely between them and the metacarpal bones, transmit the motions to the latter in a curved direction. The long axis of the wrist-joint is, as nearly as may be, at right angles to that of the elbow-joint, and more or less parallel with that of

[1] The furcula are usually united to the anterior part of the sternum by ligament; but in birds of powerful flight, where the wings are habitually extended for gliding and sailing, as in the frigate-bird, the union is osseous in its nature. "In the frigate-bird the furcula are likewise anchylosed with the coracoid bones." ("Comp. Anat. and Phys. of Vertebrates," by Prof. Owen, vol. ii., p. 66.)

[2] "The os humeri, or bone of the arm, is articulated by a small rounded surface to a corresponding cavity formed between the coracoid bone and the scapula, in such a manner as to allow great freedom of motion." (Macgillivray's "British Birds," vol. i., p. 33.)

"The arm is articulated to the trunk by a ball-and-socket joint, permitting all the freedom of motion necessary for flight." ("Cyc. of Anat. and Phys.," vol. iii., p. 424.)

the shoulder. The metacarpal or hand-bones, and the phalanges or finger-bones, are more or less fused together, the better to support the great primary feathers, on the efficiency of which flight mainly depends. They are articulated to each other by double hinge-joints, the long axes of which are nearly at right angles to each other.

As a result of this disposition of the articular surfaces, the wing is shot out or extended and retracted or flexed in a variable plane, the bones composing the wing, particularly those of the forearm, rotating on their axes during either movement.

This secondary action, or the revolving of the component bones upon their own axes, is of the greatest importance in the movements of the wing, as it communicates to the hand and forearm, and consequently to the primary and secondary feathers which they bear, the precise angles necessary for flight; it, in fact, insures that the wing, and the curtain or fringe of the wing which the primary and secondary feathers form, shall be screwed into and down upon the air in extension, and unscrewed or withdrawn from it during flexion. The wing of the bird may therefore be compared to a huge gimlet or auger; the axis of the gimlet representing the bones of the wing, the flanges or spiral thread of the gimlet the primary and secondary feathers.

The following account (with illustrations) of the movements of the bones and joints of the wing of the bird was published by me in 1867.[1]

THE MOVEMENTS PECULIAR TO THE SHOULDER, ELBOW, WRIST, AND OTHER JOINTS IN THE WING OF THE BIRD

§ 410. Shoulder-Joint.

The head of the humerus is convex and somewhat oval (not round), the long axis of the oval being directed from above downwards, that is, from the dorsal towards the ventral aspect of the bird. The humerus can, therefore, glide up and down in the *facettes* occurring on the articular ends of the coracoid and scapular bones with great facility, much in the same way that the head of the radius glides upon the distal end of the humerus. But the humerus has another motion; it moves like a hinge from before backwards, and the reverse. The axis of the latter movement is nearly at right angles to that of the former. As, however, the shoulder-joint is connected by long ligaments to the body, and can be drawn away from it to the extent of one-eighth of an inch or so, it follows that a third and twisting movement can be performed, the twisting admitting of rotation to the extent of a quarter of a turn or thereby. In raising and extending the wing preparatory to the downward stroke, two opposite movements are required, namely, one from before backwards (Fig. 519, *a*), and another from below upwards (*b*). As, however, the axes of these movements are at nearly right angles to each other, the spiral or twisting movement is necessary to run the one into the other—to turn the corner, in fact (*c*).

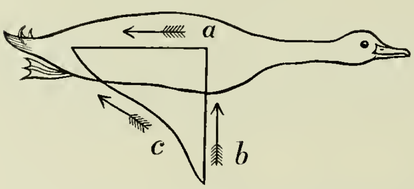


FIG. 519.—Spiral course (*c*) described by the head of the humerus when the wing is being raised and extended.

The ligaments of the shoulder-joint are cross or check ligaments, one set acting to prevent an undue elevation and backward motion, the other an undue depression and forward motion. They also act in preventing undue twisting either in a backward or forward direction. The wing of the insect is geared after a similar fashion at the axilla.

§ 411. Elbow-Joint.

The long axis of the elbow-joint intersects the long axis of the shoulder-joint nearly at right angles. When the humerus is fixed, and the wing is extended and flexed, the proximal ends of the bones of the forearm describe a spiral track on the distal end of the humerus or bone of the arm. This is proved by the conformation of the elbow joint, and by the fact that during extension the bones of the forearm, particularly their distal extremities, describe a curve from above downwards, the elbow being depressed and carried forwards.

During flexion the bones referred to describe another and opposite curve.

The trajectories made by the elbow-joint during extension and flexion may consequently be represented by an ellipse or ovoid (Fig. 520).

[1] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom." (*Trans. Linn. Soc. Lond.*, vol. xxvi., pp. 247, 248, 249, and 250.)

§ 412. Wrist-joint.

The long axis of the wrist-joint is at nearly right angles to that of the elbow, and nearly parallel with that of the shoulder. In extension of the wrist the metacarpal and phalangeal bones describe a curve from below

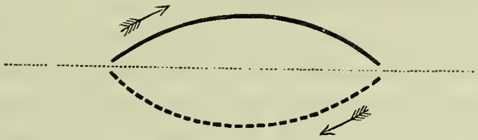


Fig. 520.

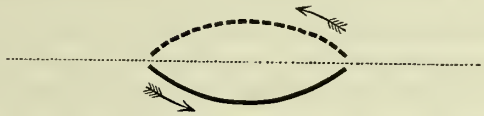


Fig. 521.

upwards, the wrist being elevated and carried backwards ; whereas in flexion, they describe another and opposite curve.

The trajectories made by the wrist-joint during extension and flexion may therefore be represented by an ovoid or ellipse (Fig. 521).

The movements of the, wrist-joint are always the reverse of those occurring at the elbow-joint. Thus, during

Fig. 522.—Extension of the Wing.

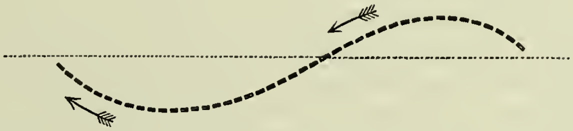


Fig. 523.—Flexion of the Wing.

extension, the elbow and bones of the forearm are elevated, and describe one side of an ellipse ; while the wrist and bones of the hand are depressed, and describe the side of another and opposite ellipse, as shown at Figs. 522 and 523.

These movements, I need scarcely observe, are reversed during flexion.

From this it follows that when the elbow is raised *and carried backwards*, the wrist is lowered *and carried forwards*, and *vice versâ*.

Similar remarks may be made regarding the disposition of the articular surfaces, and the movements of the metacarpal and phalangeal bones.

§ 413. The Elbow-, Wrist-, and other Joints Alternate and Reciprocate.

The alternating and opposite movements described by the elbow- and wrist-joints are occasioned by the bones of the elbow and wrist being spirally arranged, and from each making a quarter of a turn or so during extension, and the same amount during flexion. As a consequence, the wing, as has been explained, may be shot out or

Line along which the wing travels during extension and flexion......

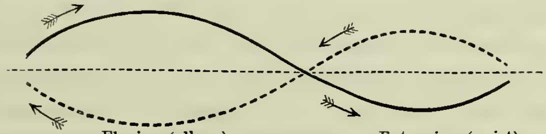


Fig. 524.

extended, and withdrawn or flexed, in a nearly straight line, the *modus operandi* or principle of action being not inadequately represented by the component parts of an auger or gimlet—the axis of the instrument representing the action of the wing as a whole, the spiral flanges the movements of the component bones and of the feathers (Fig. 524).

§ 414. Elevation and Depression of the Wing, how caused.

The object of the alternating and reciprocating movements of the elbow and wrist is the elevating and depressing of the wing during extension and flexion ; the mere act of extension raising the pinion preparatory to

its making the downward stroke, the act of flexion gathering the pinion up or off the air preparatory to a second extension. These movements are analogous in every respect to those made by corresponding parts in the bat, and by the arms in swimming.

§ 415. The Elbow-, Wrist-, and other Joints always at nearly Right Angles.

The long axis of the elbow-, wrist-, and other joints during *extreme extension* is always the reverse of what it is during *extreme flexion;* but whatever the direction of the axis of one joint, the axis of the joint next to it is always nearly at right angles. The joints in this manner co-ordinate and complement each other The conformation of the elbow-, wrist-, and other joints, and the movements of the bones of the hand on the forearm, and of the forearm on the humerus, account for the wing of the bird and bat being twisted upon themselves, and for their peculiar spiral mode of action. In the insect, where the wing as a rule is not jointed (unless where attached to the body), the spiral twist is impressed on the pinion at first and retained.

§ 416. Lateral Movements in the Elbow-, Wrist-, and other Joints.

In addition to the movements described by the elbow- and wrist-joints during extension and flexion, a considerable degree of lateral motion is permitted. This is best seen by fixing the humerus, and then rotating the forearm upon it, or by fixing the forearm and rotating the hand upon that.

If the bird be placed with its head away from the spectator, and the forearm be rotated towards him, the motion at the elbow will be found most extensive in *an upward and backward direction;* the reverse of this holding true of the wrist-joint. The same may be said of the metacarpal and phalangeal joints; so that the bones of the hand twist upon the metacarpal, the metacarpal on the carpal, the carpal on the radius and ulna, and the radius and ulna upon the humerus. The alternating spiral arrangement is also manifest in the disposition of the bones of the wing—the ulna, which is the principal bone of the forearm, curving *from below upwards,* while the metacarpal and phalangeal bones curve *from above downwards.* Advantage is taken of this circumstance to transfer the spiral arrangement of the osseous structures to the feathers principally employed in flight, the metacarpal and phalangeal bones supporting the primary feathers, the ulna the secondary ones. This coincidence in the arrangement of the bones of the wing and the feathers thereof is necessary, because the bones of the forearm and hand, as has been explained, revolve upon their axes during extension and flexion, and in so doing they rotate the primary and secondary feathers on and off the air, and give them the precise angles necessary for flight.

It is a curious circumstance that the movements described by the forearm and hand of the bird are analogous to those described by the serpent when creeping and the fish when swimming.

TRACES OF DESIGN IN THE WING OF THE BIRD—THE ARRANGEMENT OF THE PRIMARY, SECONDARY, AND TERTIARY FEATHERS, &c.

There are few things in nature more admirably constructed than the wing of the bird, and perhaps none where design can be more readily traced. Its great strength and extreme lightness, the manner in which it closes up or folds during flexion, and opens out or expands during extension, as well as the manner in which the feathers are strung together and overlap each other in divers directions to produce at one time a solid resisting surface, and at another an interrupted and comparatively non-resisting one, present a degree of fitness to which the mind must necessarily revert with pleasure. If the feathers of the wing only are contemplated, they may be conveniently divided into three sets of three each (on both sides of the wing)—an upper or dorsal set, a lower or ventral set, and one which is intermediate. This division is intended to refer the feathers to the bones of the arm, forearm, and hand, but is more or less arbitrary in its nature. The lower set or tier consists of the primary, secondary, and tertiary feathers, strung together by fibrous structures in such a way that they move in an outward or inward direction, or turn upon their axes, at precisely the same instant of time—the middle and upper sets of feathers, which overlap the primary, secondary, and tertiary ones, constituting what are called the "coverts" and "sub-coverts." The primary or rowing feathers are the longest and strongest, the secondaries next, and the tertiaries third. The tertiaries, however, are occasionally longer than the secondaries. The tertiary, secondary, and primary feathers increase in strength from within outwards, that is, from the body towards the extremity of the wing, and so of the several sets of wing-coverts. This arrangement is necessary, because the strain on the feathers during flight increases in proportion to their distance from the trunk.

In flexion the feathers open up and permit the air to pass between them. In extension they flap together

and render the wing as air-tight as that of either the insect or bat. The primary, secondary, and tertiary feathers have consequently a valvular action.

It is questionable whether in the whole range of biology a better example of design could be found than is afforded by the wing of the bird. Its uniformly triangular shape, with the acute angle directed outwards to make the tip of the wing light; its concavo-convex form, with the convex surface directed upwards to reduce friction and resistance during the up stroke, and its concave surface directed downwards to increase friction and resistance during the down stroke; its carefully graduated structure, whereby it is thickest and strongest at the root and along its anterior margin, and thinnest at its tip and along its posterior margin; its unequal yielding to air pressure during the up and down strokes which necessitate its continuous *forward* travel; its wonderful mobility and elasticity, due to its joints and the springy nature of the materials composing it; its great sensitiveness, which enables it to feel and utilise every conceivable kind of air current; its reciprocating action, which enables it to draw after it and form two sets of artificial air currents on which flight largely depends; its muscular movements, which alternately flex and extend the wing, converting the organ into a short lever during the up stroke and into a long lever during the down stroke; its beautiful universal and spiral joints, which confer on it every possible variety of movement—upward, downward, forward, backward, and oblique movements, movements of circumduction, rotation, abduction, adduction, &c.; its exquisite figure-of-8 reversing curves which, during flight, literally entangle and entrap the air; its extraordinary wealth of concavo-convex feathers—primary, secondary, and tertiary, all graduated and specialised—those being longest and strongest at the tip of the wing, where the air pressure is greatest, and shortest and feeblest at the root of the wing, where the air pressure is least; its marvellous osseous modifications, whereby the hand (partly by suppression at one point, partly by undue growth at another, and partly by coalescence and fusion) is enormously increased in size and strengthened for the purposes of flight; all combine to render the wing of the bird one of the most marvellous organs in existence.[1] The wing is a veritable stronghold of design, alike from the structural and functional side; and nothing short of original endowment and prevision of the highest order can account for its presence in the animal kingdom. Certainly no form of evolution or natural selection can adequately account for its extraordinary modifications and excellencies as the instrument of flight.

§ 417. Flexion and Extension of the Wing of the Bird in Flight.

The flexion and extension of the wing of the bird in flight is an absolute necessity. Means had to be found for evading more or less completely the superimposed air during the up stroke of the wing, and for seizing the nether air during the down stroke. This is done by converting the wing into a short lever during flexion and the up stroke, and into a long lever during extension and the down stroke. The wing in the flexed state is only half the length of what it is in the extended state (see Plate clxxiv., p. 1265).

This, of itself, goes far to counteract the operation of gravitation on the wings and body of the volant animal when progressing in the air. The power of gravitation is further neutralised by the primary, secondary, and tertiary feathers being separated and opened out to let the air pass between them during flexion and the up stroke. These feathers present oblique knife edges to the superimposed air when the wing is being elevated. It is not, however, to be inferred that the wing ceases to be effective as a flying organ during the up stroke. In flexion, the individual feathers act separately and independently as miniature kites, and, by their combined action, convert the wing into a larger kite, the under concave surface of which, making various angles with the horizon as it ascends, secures for it a considerable degree of elevating and propelling power. The power of gravitation is still more reduced by the wing always presenting its upper convex surface to the air during flexion and the up stroke, and its under concave surface during extension and the down stroke.

The amount of flexion of the wing in flight varies in the several kinds of birds. It is greatest in rowing or flapping flight and least in soaring, sailing, or gliding flight. It occurs chiefly at the wrist-joint. The flexing and folding of the wing occurs not only in flight, but also when the wings are tucked up and stowed away on the back of the bird when not flying. The flexion of the wing, it will be seen, serves a double purpose.

The short and long levers formed by the wing during flexion and the up stroke, and during extension and the down stroke, are shown in the sea-gull at A, B, C, and D of Fig. 525; in the snipe at Fig. 514, p. 1244; in the pheasant at Fig. 516, p. 1245; and in the pigeon at Plate clxxiv., p. 1265.

[1] In the wing of the bird, several of the bones of the wrist and hand are suppressed; certain of the bones of the hand being enlarged, strengthened, fused, and welded together to support the long, powerful primary or rowing feathers on which flight mainly depends. In the bat, the first digit or thumb is suppressed and converted into a hook, whereby the animal suspends itself from projections in an inverted position when at rest. In the pterodactyl, an extinct flying reptile, the hallux or first finger is suppressed, and the second, third, and fourth are aborted and provided with claws; the fifth digit being enormously increased in length and strength for the purpose of supporting the flying membrane.

When I first discussed the flexion and extension of the wing in 1867 [1] the subject was involved in considerable obscurity. The following is the description given by me at that date: Considerable diversity of opinion exists as to whether birds do or do not flex their wings in flight. The discrepancy is owing to the great difficulty experienced in analysing animal movements, particularly when, as in the case of the wings, they are consecutive and rapid. My own opinion is, that the wings are flexed during flight, but that all wings are not flexed to the same extent, and that what holds true of one wing does not necessarily hold true of another. To see the flexing of the wing properly, the observer should be either immediately above the bird or directly beneath it. If the bird be contemplated from before, behind, or from the side, the up and down strokes of the pinion distract the attention and complicate the movement to such an extent as to render the observation of little value. In watching rooks proceeding leisurely against a slight breeze, I have over and over again satisfied myself that the wings are flexed during the up stroke, the mere extension and flexion, with very little of a down stroke, in such instances sufficing for propulsion. I have also observed it in the pigeon in full flight, and likewise in the starling, sparrow, kingfisher, and sea-gull (Fig. 525).

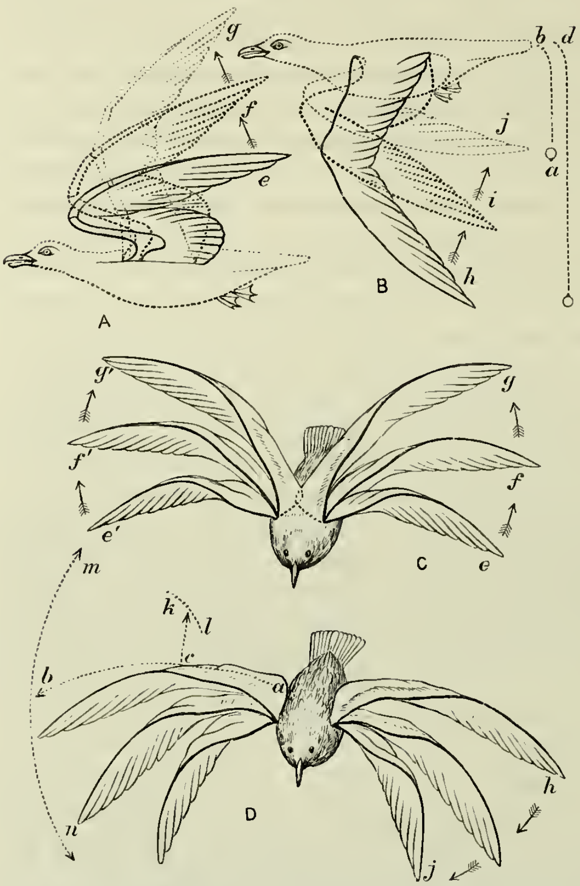


Fig. 525.—Lateral and frontal views of the sea-gull, showing how the wings are flexed and converted into short levers during the up strokes, and extended and converted into long levers during the down strokes.

A. Lateral view. *e, f, g,* The wing being elevated as a short lever and extended towards the end of the up stroke to prepare it for making the down stroke.

B. Lateral view. The wing being depressed as a long lever (*h*). At the end of the down-stroke it is suddenly flexed as at *i, j,* and converted into a short lever (*j*), in which condition it makes the up stroke. The short lever is seen at *a, b*; the long one at *c, d*. The short lever made by the wing in flexion is only half that made by the wing in extension.

C. Frontal view. *e, f, g, e', f', g',* The wings being elevated as short levers and gradually extended towards the end of the up stroke to prepare them for making the down stroke.

D. Frontal view. The wings descending in the extended state as long levers and being suddenly flexed at the end of the down stroke to prepare them for making the up stroke. *a, b,* Gives the length of the wings; *m, n,* the range of the wing movements during the up and down strokes; *k, l,* the rotation of the wings along their anterior margins with *c* as an axis; *j,* the flexing of the wings at the end of the down stroke to prepare them for making the up stroke. The wing moves outwards at the end of the up stroke and inwards at the end of the down stroke—the tip of the wing describing an ellipse (the Author, 1867 and 1870).

It seems to occur principally at the wrist-joint, and gives to the wing the peculiar quiver or tremor so apparent in rapid flight, which is likewise well seen in young birds at feeding-time. The object to be attained is manifest. By the flexing of the wing in flight, the "*remiges*," or rowing feathers, are opened up or thrown out of position, and the air permitted to escape—advantage being thus taken of the peculiar action of the individual feathers and the higher degree of differentiation perceptible in the wing of the bird as compared with that of the bat and insect.

In order to corroborate the above opinion, I extended the wings of several birds and fixed them in the outspread position by lashing them to light, unyielding reeds. In these experiments the shoulder and elbow-joints were left quite free—the wrist or carpal and the metacarpal joints only being bound. I took care, moreover, to interfere as little as possible with the action of the elastic ligaments or alar membranes which, in ordinary circumstances, recover or flex the wing, the reeds being attached for the most part to the primary and secondary feathers. When the wings of a pigeon were so tied up, the bird could not rise, although it made vigorous efforts to do so. When dropped from the hand, it fell violently on the lawn, notwithstanding the strenuous exertions which it made with its pinions to save itself. When thrown into the air, it fluttered most energetically in its endeavours to reach the dovecot, which was close at hand. In every instance, however, it fell, more or less heavily, the distance attained varying with the altitude to which it was projected.

Thinking that probably the novelty of the situation and the strangeness of the appliances confused the bird, I allowed it to walk about and to rest without removing the reeds. I repeated the experiment at intervals, but with no better results. The same phenomena, I may remark, were witnessed in the sparrow; so that I think there can be little doubt that a certain degree of flexure is indispensable to the flight of all birds—the amount varying according to the length and form of the pinion, and being greatest in the short, broad-winged birds, as the partridge

[1] *Trans. Linn. Soc.*, vol. xxvi., read before the Linnean Society on the 6th and 20th of June, 1867.

and kingfisher, less in those whose wings are moderately long and narrow, as the gulls and many of the oceanic birds, and least in the heavy-bodied, long and narrow-winged sailing or gliding birds, the best example of which is the albatross. The degree of flexion, moreover, varies according as the bird is rising, falling, or progressing in a horizontal direction, it being greatest in the two former, and least in the latter.

The wing in flexion is drawn towards the body of the bird at the end of the down stroke. It is shot out or away from the body in extension at the end of the up stroke. The tip of the wing during these movements, and during the up and down strokes, describes a combined oval and elliptical trajectory in space.

A certain amount of preparation is required before the bird can make the down stroke ; the wing must be shot outwards, the primary, secondary, and tertiary feathers closed, and the angles which it makes with the horizon arranged. Similarly, before the up stroke can be made, the wing must be drawn inwards and flexed, and the primary, secondary, and tertiary feathers separated and opened up, to let the superimposed air pass through them. One complete oscillation of the wing may be conveniently divided into four stages, all of which glide into each other ; namely (*a*) flexion of the wing prior to the up stroke ; (*b*) the up stroke ; (*c*) extension of the wing prior to the down stroke ; (*d*) the down stroke.

My views as to the flexing and shortening of the wing during the up stroke, and the extending and elongating

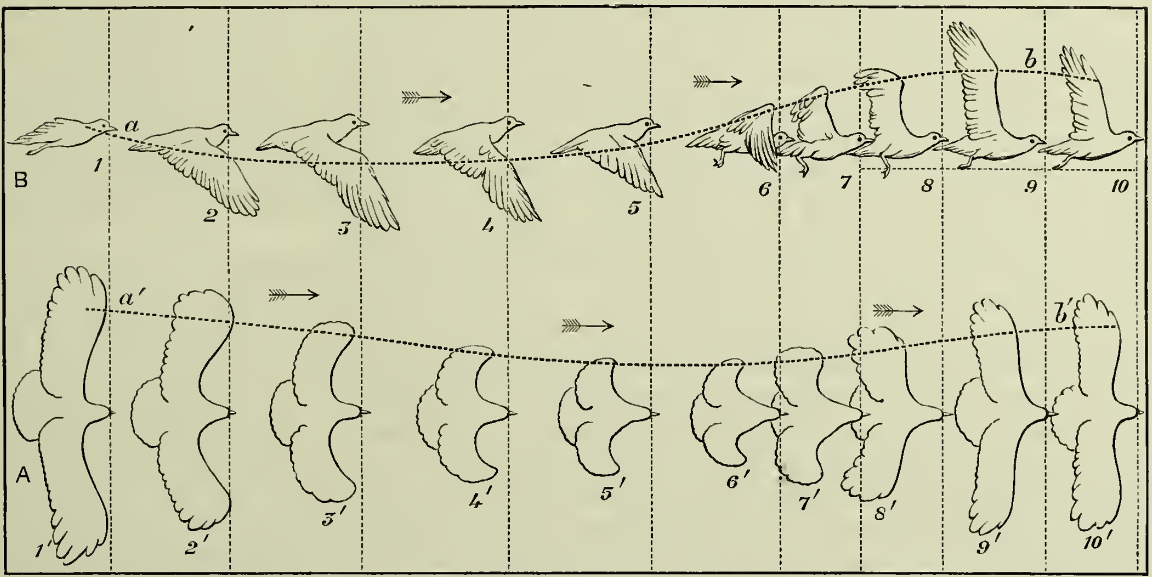


Fig. 526.—Diagram of synoptic views of the projections made by the wing at ten successive periods of one revolution. The curved lines *a*, *b*, and *a′*, *b′*, in the figure represent the points where the wings are folded or flexed, and where they are spread out or extended during flight. Extract of a Memoir "On the Movements of the Wing of the Bird in three Dimensions of Space" by Professor E. J. Marey. (*Comptes Rendus des Séances de l'Académie des Sciences*, tom. iv., meeting of February 7, 1887.) (Compare this figure with Fig. 525.)

of the wing during the down stroke, which I described and illustrated in 1867 [1] and more fully in 1870,[2] were strikingly confirmed by the aid of instantaneous photography by Professor E. J. Marey of Paris in January 1887, seventeen years after my observations and experiments on the subject were published.

I had, in due course, presented copies of my 1867 and 1870 memoirs to Professor Marey, and I now append his instantaneous photographs corroborating in the fullest manner my several descriptions and delineations.

It is true that in insects, unless perhaps in those which fold or close the wing during repose, no flexion of the pinion takes place in flight, but this is no argument against this mode of diminishing the wing-area during the up stroke, and the increasing of the wing-area during the down stroke where joints exist ; and it is all but certain that when joints are present they are added to augment the power of the wing during its active state, that is, during flight, rather than to assist in arranging the pinion on the back or side when the wing is passive and the animal is reposing. The flexion of the wing is most obvious when the bird is exerting itself in rapid flight, and may be detected in birds which skim or glide when they are rising, or when they are vigorously flapping their wings to secure the impetus necessary to the gliding movement. It is less marked at the elbow-joint than at the wrist ; and it may be stated generally, that as the amount of flexion *decreases*, the twisting, flail-like movement of the

[1] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom." (*Trans. Linn. Soc. Lond.*, vol. xxvi., pp. 252, 253, and 254, Fig. 17.)

[2] "On the Physiology of Wings." (*Trans. Roy. Soc. Edin.*, vol. xxvi., pp. 377, 378, 379, 380, 381, 382, and 383.)

wing at the shoulder *increases*, and *vice versâ*; the great difference between sailing birds and those which do not sail amounting to this, that in the sailing birds the wing is worked from the shoulder by being alternately rolled on and off the wind as in insects; whereas, in birds which do not glide, the spiral movement travels along the arm, and manifests itself during flexion and extension in the bending of the joints and in the rotation of the bones of the wing on their axes. The spiral conformation of the pinions, to which allusion has been so frequently made, is best seen in the heavy-bodied birds, such as the turkey, capercailzie, pheasant, and partridge, and here also the concavo-convex form of the wing is most perceptible. In the light-bodied, ample-winged birds, the amount of twisting is diminished, and, as a result, the wing is more or less flattened.

THE WING STRIKES UPWARDS AND *FORWARDS* DURING THE UP STROKE AND DOWNWARDS AND *FORWARDS* DURING THE DOWN STROKE

If the wing of a large bird, say the gannet, be detached at the shoulder-joint from the body immediately the bird is killed, and when all the soft tissues are flaccid and the joints supple, it is found that the wing is more or less self-acting. Thus, when the wing (which is naturally flexed) is caught at the root by the hand, and suddenly elevated as in flight, it darts upwards and forwards in a curve; the wing extending itself towards the end of the up stroke to prepare it for making the down stroke. When, in like manner, the wing is suddenly depressed as in flight, it leaps downwards and forwards in a curve, the wing folding at the end of the down stroke. When the upward forward and downward forward curves are united, as happens if the upward and downward movements are repeated quickly, they form the waved trajectory characteristic of progressive flapping flight. The extending of the wing at the end of the up stroke and the partial closing of it at the end of the down stroke, as well as the flying forward of the wing during the up and down strokes, are quite independent of any power conferred or bias given by the operator. The phenomena witnessed are invariably the same.

During the down stroke the wing of the gannet travels more than three feet forwards. This was an altogether unlooked for result, and wholly opposed to our preconceived notions of what the movements of the wing should be.

Until I had performed the above simple experiment, and made similar experiments with artificial wings constructed on the pattern of the living pinion, it was the universal belief that the wing acted in a strictly vertical direction during the up and down strokes, and that during the down stroke the wing struck either vertically downwards or downwards and *backwards*. Thus Mr. Macgillivray, in his "History of British Birds," published in 1837, says that in flexion the wing is drawn upwards, forwards, and inwards, but that during extension, when the effective stroke is given, it is made to strike outwards, downwards, and *backwards*. The late Duke of Argyll held a similar opinion. In speaking of the hovering of birds, he states that, "if a bird, by altering the axis of its own body, can direct its wing-stroke in some degree *forwards*, it will have the effect of *stopping* instead of promoting progression;" and that, "except for the purpose of *arresting* their flight, birds can never strike except *directly downwards*—that is, directly against the opposing force of gravity." [1]

Mr. Bishop says, "In consequence of the planes of the wings being disposed either *perpendicularly or obliquely backwards* to the direction of their motion, a corresponding impulse is given to their centre of gravity." [2] Professor Owen, in like manner, avers that "a downward stroke would only tend to raise the bird in the air; to carry it forwards, the wings require to be moved in an oblique plane, so as to *strike backwards* as well as downwards." [3]

The following is the account given by M. E. Liais: "When a bird is about to depress its wing, this is a little inclined from before backwards. When the descending movement commences, the wing does not descend parallel to itself in a direction from before backwards; but the movement is accompanied by a rotation of several degrees round the anterior edge, so that the wing becomes more in front than behind, and the *descending movement is transferred more and more backwards*. . . . When the wing has completely descended, it is both *further back* and lower than at the commencement of the movement." [4]

I was induced to perform the experiments referred to above with the natural and artificial wing from having observed that birds in settling upon and on leaving the water, and in rising from the ground, invariably cause their wings to strike downwards and *forwards* during the down stroke. This seemed paradoxical and contrary to the accepted tenets of physics, as based on action and reaction. It was universally believed that in order to get an upward recoil the wing must strike vertically downwards, but if an upward and forward recoil was desired the wing must strike downwards and *backwards*. This reasoning applies to an unyielding fulcrum, such as the earth, struck by a rigid or semi-rigid body, say the hoof of a horse. It also holds partly true of the water as a yielding fulcrum

[1] *Good Words*, Feb. 1865, p. 132.
[2] "Cyc. of Anat. and Phys.," vol. iii., p. 425.
[3] "Comp. Anat. and Phys., Vertebrates," vol. ii., p. 115.
[4] "On the Flight of Birds and Insects." (*Annals of Nat. Hist.*, vol. xv., 3rd series, p. 156.)

struck by a semi-rigid lever such as the foot of a swimming bird, but it is not true of the elastic swimming and diving wing, and still less true of the more highly elastic aërial wing expressly adapted to act upon the highly compressible, yielding air. The wing as a lever, and the air as a fulcrum, are quite peculiar, and the ordinary formulæ of physics are not applicable.

When, however, I found that the natural wing, and the artificial wing constructed on the natural wing type, invariably gave the same results, I felt an explanation must be forthcoming. The explanation lies in the shape and construction of the wing, in its elasticity, in its unequal yielding during the up and down strokes, and in its having as its fulcrum or objective the thin, mobile, highly elastic, practically intangible air. In order to get a recoil from the thin, mobile, yielding air the wing must strike it quickly and with immense force. The moment the wing strikes the air, say in the down stroke, it travels *forwards* in the direction of the head of the bird. This it does mainly by the yielding of the posterior margin of the wing. The descending wing in flying forwards elevates the bird and in so doing *pulls* the body of the bird upwards and forwards. The old idea was that the wing *pushed* the body upwards and forwards. The result is the same, but the *modus operandi* is entirely different. When the bird is once launched in space, the necessity for the forward action of the wing during the up and down strokes becomes more manifest. The bird floating forward in space is a body in motion tending to fall in a downward and forward direction. A bird shot on the wing never falls vertically downwards; its acquired momentum necessitates its falling downwards and forwards in a curve. It follows, that if the wings are to give support to the flying bird they must be carried, as much as possible, in front of the body of the bird. This explains the forward action of the wing during the up and down strokes. If the wings, during the down stroke, were to strike downwards and *backwards*, and so deprive the bird of its advance supports, it would turn a series of forward somersaults. The matter is, moreover, one of common sense, and may be put thus. The wings, as every one admits, are the organs by the aid of which the bird flies. If, however, the wings did not themselves fly forward, how could they by any possibility inaugurate or continue flight? It may astonish some of my readers when I tell them that the tip of the wing towards the end of the down stroke is often more than two-thirds the length of the body in advance of the beak of the bird.

My views regarding the forward action of the wing during the up and down strokes, published in 1867, met with quite a storm of opposition on the part of the physicists and mathematicians at home and abroad. The Cambridge mathematicians were especially hostile. I was told that my physics were all wrong, that they controverted the laws of Newton, &c. This controversy raged for several years.

About the year 1870, my friend the late Sir George Murray Humphrey, the well-known Professor of Anatomy in the University of Cambridge, visited me in Edinburgh, where I was then residing, and I took him to my laboratory and showed him my collection of natural and artificial wings. He was particularly struck with what he saw, and when I taught him how to elevate and depress the wings so as to elicit the forward movements, he became fairly excited, and exclaimed, "Now you must come to me on a visit to Cambridge, and I will provide you with a distinguished and representative audience, and we will instruct and confute, if we do not convince, the non-believers." I did not accept Sir George's kind offer and services. I was very busy at the time, and told him that my observations and experiments were published, and that I feared there would be little chance of converting closet philosophers, who elected to talk theoretical physics, and who did not take the trouble to repeat my experiments. Moreover, I had done my work, and it was a matter of no great concern to me whether my views on wing movements were accepted or not.

As the subject of flight had been treated by me from an entirely new point, I had many visitors during my sojourn in Edinburgh. Among them was the genial Professor Piazzi Smyth, the distinguished Astronomer Royal for Scotland. I put a large artificial wing (6 feet long and 15 inches wide) in his hands. I then asked him to elevate the wing, shut his eyes, and depress the wing with all the force at his command. I requested him to shut his eyes to prevent his exercising any undue restraining influence on the movements of the wing in favour of possible preconceived ideas. The result was remarkable, and, as it turned out, somewhat serious for the Professor. The great wing descended with a downward and forward swoop, whirled the Professor round, and caused him to rotate quite half a circle, with the result, that he unfortunately got twisted and strained at the loins and was confined to bed for nearly a fortnight after the experiment.

The forward movement of the wing during the up and down strokes is of the very essence of flight. It practically lies at the bottom of all wing movements.

The following is the account given of it by me in 1867: The effective strokes in insects (and this holds true also of birds and bats) is delivered *downwards* and *forwards*, and not, as is commonly believed, *vertically*, or even *slightly backwards*. This arises from the curious circumstance that insects, birds, and bats, when flying, actually fall through the medium which elevates them, their course being indicated by the resultant of two forces, namely,

that of gravity pulling vertically downwards, and that of the wing acting at a given angle in an upward direction. In those birds, insects, and bats which flap the wings leisurely, the stroke is delivered in an almost perpendicular direction, the wing, by rotating on its axis from behind forwards, causing the under surface of the pinion to act upon the air obliquely *from above downwards* and from *behind forwards*. The down stroke in slow-flying creatures is delivered nearly at right angles to the body, which is inclined in a slightly upward direction. The upward inclination of the body, and the comparative perpendicularity of the stroke, is necessary to counteract the tendency of the slow-flying animals to fall *vertically downwards*. In those insects, birds, and bats, however, whose wings are moved with great celerity and the speed attained is high, the down stroke is inclined *very decidedly forwards*—the tendency of the body to fall *downwards* and *forwards* increasing as the speed of the wing and the velocity of flight are augmented.

I append my original figure and description illustrating the downward and *forward* double-curve movement made by the wing of the bird during the down stroke, first published in 1867.[1]

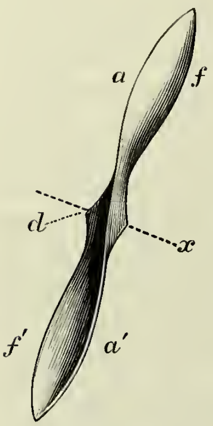


Fig. 527.

Fig. 527.—Blur or impression produced on the eye by the rapid oscillation of the left wing of the bird. Seen from the left side. Shows how the wing rotates or twists on its long axis, and describes a spiral track, *a, a′*, during its descent and ascent. It also shows that the down, or effective stroke, is delivered obliquely downwards and forwards, and not vertically or slightly backwards, as is generally stated. During the return or up stroke the movement is reversed. *x*, Long axis of the body, which may be regarded as running through the root of the wing, the body being inclined upwards as in flight; *d*, root of wing; *d, f*, anterior or thick margin when the wing is elevated preparatory to the down stroke; *d, f′*, anterior or thick margin when the wing is depressed, as happens at the termination of the down stroke; *a, a′*, spiral track described by the posterior or thin margin of the wing during its descent and ascent. A careful examination of this figure will show that the anterior or thick margin and the posterior or thin margin of the wing describe different curves, these curves, when the wing is in motion, crossing each other (the Author, 1867).

The forward movement of the wing during the down or effective stroke is particularly evident in birds when rising; the wing, on such occasions, being urged with unusual vigour. The forward movement of the wing during the down stroke is singularly well seen in young pigeons when thrown from the hand for the first time; and I have noticed it in the cormorant when leaving the water; this bird, because of its great weight, rising with considerable difficulty. It is also well seen in the sea-gull. The forward movement of the wing during its descent is seen to advantage in the flight of the wild goose and duck, both of which fly with immense velocity. It can be increased and diminished at pleasure, and assists in regulating the rapidity of flight. The wing, in slow flying insects, bats, and birds, supports the centre of gravity by playing, as it were, alternately above and beneath it; whereas in those of rapid flight, the pinion plays obliquely on either side of it. The sustaining area of the wings is greatly increased in birds, insects, and bats of rapid flight; and this is owing partly to the oblique direction of the stroke, and partly to the fact that the quickly vibrating wing, practically speaking, occupies the entire space marked off by the down and up strokes, in the same way that the spokes of a wheel in rapid motion apparently fill every part of the area contained within its rim.

That the forward movements of the wing during the up and down strokes are real and not imaginary is proved beyond doubt by the beautiful instantaneous photographs of flying birds by Mr. E. Muybridge of Pennsylvania, America. This gentleman commenced his photographic operations in 1872, and completed them in 1882. By the aid of electricity he took a large number of instantaneous photographs of quadrupeds and bipeds, including birds, at short and regulated intervals of time. These photographs are intended to show the consecutive movements of the more common terrestrial animals as they progress on the land, and of the well-known birds as they fly in the air. Amongst flying birds he gives instantaneous photographs of the flight of the pigeon and cockatoo. Of these I append selections (see Plate clxxiv.).

They show the following important points :—

(*a*) That the wing is flexed or folded and the feathers separated and opened up during the up stroke;

(*b*) That the wing is elevated as a short lever;

(*c*) That the wing is extended to its full dimensions and the feathers closed during the down stroke.

(*d*) That the wing is depressed as a long lever;

[1] *Trans. Linn. Soc. London*, vol. xxvi., Plate xv., Fig. 61.

PLATE CLXXIV

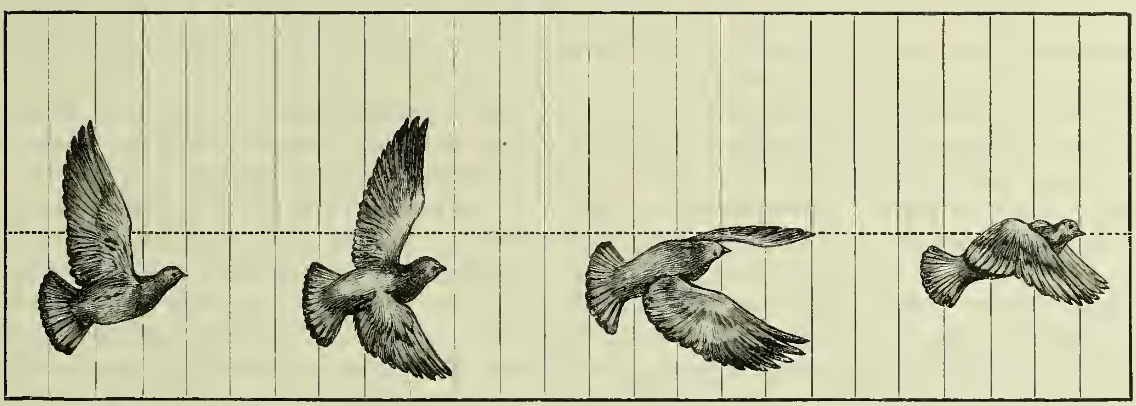


FIG. 1. FIG. 2. FIG. 3. FIG. 4.

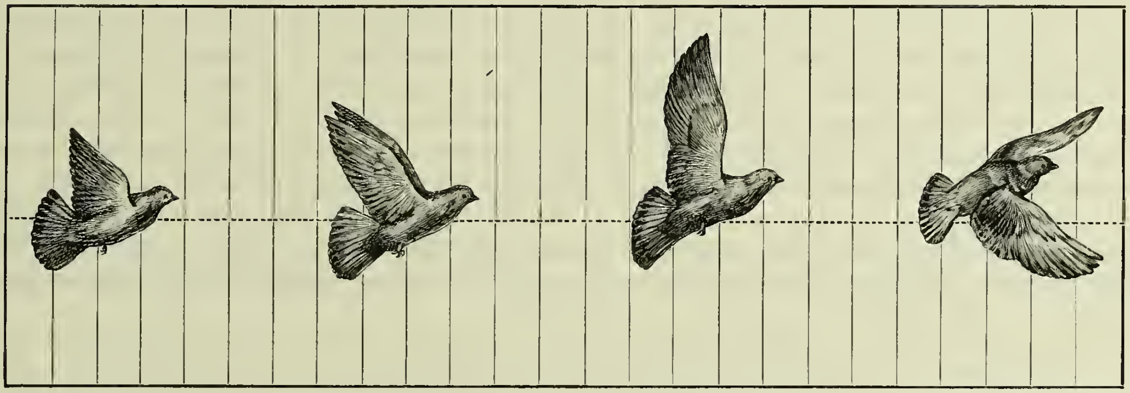


FIG. 5. FIG. 6 FIG. 7. FIG. 8.

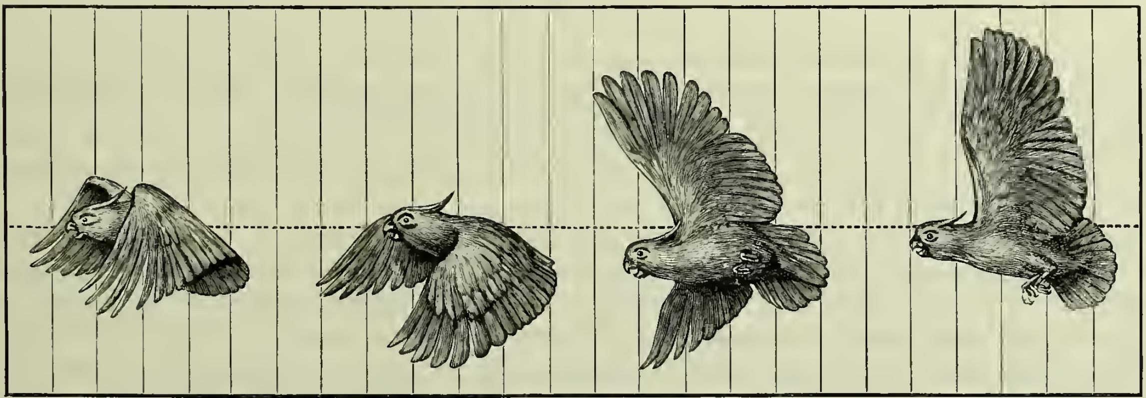


FIG. 9. FIG. 10. FIG. 11. FIG. 12.

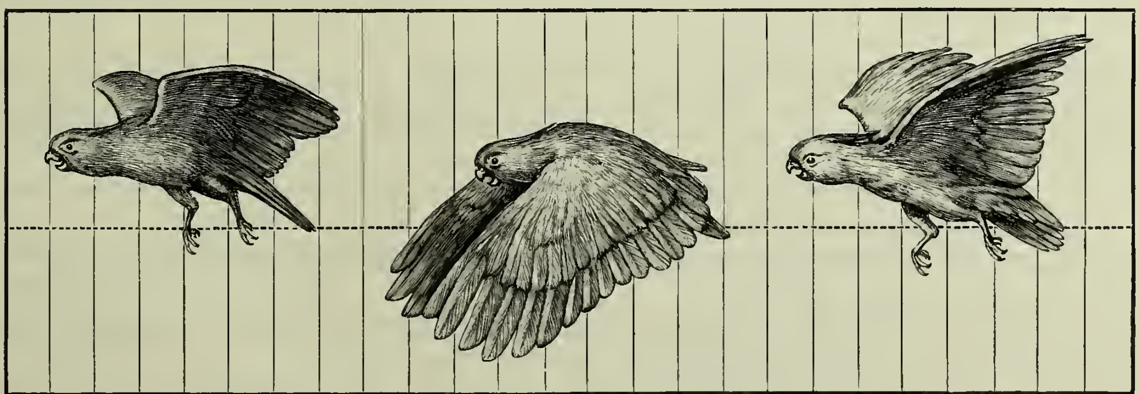


FIG. 13. FIG. 14. FIG. 15

(*e*) That the wing during the down stroke (and this is important in the present connection) descends in a downward and *forward* direction—the tip of the wing at the end of the down stroke being, in many cases, quite two-thirds the length of the body in advance of the beak of the bird; whereas at the beginning of the down stroke it is on a line which intersects the root of the tail.

These photographs settle, once and for all, the much disputed *forward* action of the wing during the up and down strokes. From the instantaneous photograph there is no appeal in animal locomotion, and the axioms of physics and applied mathematics may safely be set aside if they clash with the results so obtained.

At Fig. 1 of Plate clxxiv., the wing of the pigeon is raised high above the bird, fully extended, and its feathers closed. It is descending as a long lever in a *forward* direction At Fig. 2, the wing has descended somewhat, and advanced considerably. At Fig. 3 (end of the down stroke), it is much below the body of the bird and far in advance of its beak. Of this there cannot be a shadow of doubt. At Fig. 4, the wing is being flexed, and its feathers separated, as happens at the beginning of the up stroke. At Fig. 5, the wing is being elevated as a short lever. At Fig. 6, the wing is being elevated and gradually extended to prepare it for making the down stroke. At Fig. 7, the wing is fully extended and its feathers closed. It is now in a position to make a second down stroke. Fig. 8 represents the wing descending and flying *forwards*.

Similar results are witnessed in the cockatoo. At Fig. 12, the wing is elevated high above the bird, fully extended, and making the down stroke. At Fig. 11, the wing is descending in a downward and *forward* direction. At Fig. 10, the wing is being flexed and shortened preparatory to making the up stroke. At Fig. 9, the wing is fully flexed and the feathers separated and opened up, and presenting knife edges to the superimposed air. The wing is being elevated as a limp, short lever, which reduces the friction experienced by its upper surface to a minimum. At Fig. 15 (beginning of the down stroke), the wing is fully extended and the feathers closed to increase the bite of the under concave surface of the wing to a maximum. It is descending as a long lever. At Fig. 14 (end of the down stroke), the tip of the wing is far in advance of the beak of the bird. At Fig. 13, the wing is flexed and three-fourths elevated. When it is fully elevated and extended it is in a position to deliver a second down stroke (Plate clxxiv.).

PLATE CLXXIV

Plate clxxiv.—Shows the various phases through which the wing passes during the up and down strokes in the flight of the pigeon and cockatoo, as revealed by instantaneous photography. Figs. 1 to 8 illustrate the wing movements in the flight of the pigeon, and Figs. 9 to 15, those of the cockatoo.

Fig. 1.—The wings of the pigeon (*Columba livia*) fully elevated and extended, and about to deliver the down stroke in a downward and *forward* direction as long levers.

Fig. 2.—The wings descending and *advancing* as seen at mid stroke.

Fig. 3.—The wings at the end of the down stroke. They have, during their descent, *flown forwards,* and are now in advance of the beak of the bird by quite two-thirds of the length of the body. This is a very striking and instructive fact.

Fig. 4.—The wings partially flexed and shortened, and preparing to make the up stroke.

Fig. 5.—The wings fully flexed, and making the up stroke in a *forward* direction as a short lever.

Fig. 6.—The wings towards the end of the up stroke partly extended to prepare them for making a second down stroke.

Fig. 7.—The wings fully extended and elevated and about to make a second down stroke. The wings *have travelled forwads* during their ascent. Compare the tips of the wings in Fig. 7 with the tips of the wings in Fig. 5.

Fig. 8.—The wings *flying downwards and forwards* as in a second down stroke.

Fig. 9.—The wings of the cockatoo (*Cacatua galerita*) fully flexed and making the up stroke as a short lever. The primary and secondary feathers of the wing are separated, thrown out of gearing, and present knife edges to the superimposed air and permit it to escape and reduce friction to a minimum.

Fig. 10.—The wings partly flexed and preparing to make the up stroke.'

Fig. 11.—The wings descending and *travelling forwards.*

Fig. 12.—The wings fully elevated and extended, and about to make the downward and *forward* stroke as a long lever.

Fig. 13.—The wings ascending as a short lever.

Fig. 14.—The wings at the end of the down stroke. They have descended in a downward and *forward* direction as a long lever, and the tips of the wings, as in Fig. 3, are greatly in advance of the beak of the bird.

Fig. 15.—The wings being elevated, extended, and the primary and secondary feathers closed prior to making a second down stroke.

§ 418. Reasons why the Effective Stroke should be delivered Downwards and Forwards.

The wings of all birds, whatever their form, act by alternately presenting oblique and comparatively non-oblique surfaces to the air—the mere extension of the pinion, as has been shown, causing the primary, secondary, and tertiary feathers to roll down till they make an angle of 30° or so with the horizon, in order to prepare it for giving the effective stroke, which is delivered, with great rapidity and energy, in a *downward* and *forward* direction. I repeat, "downwards and forwards," for a careful examination of the relations of the wing in the dead bird, and a close observation of its action in the living one, supplemented by a large number of experiments with natural and artificial wings, have fully convinced me that the stroke is invariably delivered in this direction. If the wing struck downwards and *backwards* it would act at a manifest disadvantage :—

1st. Because it would present the back or convex instead of the concave surface of the wing to the air—a convex surface dispersing or dissipating the air, while a concave surface gathers it together or focuses it.

2nd. In order to strike backwards effectually, the concavity of the wing would also require to be turned backwards ; and this would involve the depression of the anterior or thick margin of the pinion, and the elevation of the posterior or thin one, during the down stroke, which never happens.

3rd. The strain to which the pinion is subjected in flight would, if the wing struck *backwards*, fall, not on the anterior or strong margin of the pinion formed by the bones and muscles, but on the posterior or weak margin formed by the tips of the primary, secondary, and tertiary feathers—which is not in accordance with the structure of the parts.

4th. The feathers of the wing, instead of being closed, as they necessarily are, by a downward and *forward* movement, would be inevitably opened, and the integrity of the wing impaired, by a downward and *backward* movement.

5th. The disposition of the articular surfaces of the wing (particularly that of the shoulder-joint) is such as to facilitate the downward and *forward* movement, while it in a great measure prevents the downward and *backward* one.

6th and lastly. If the wing did in reality strike downwards and *backwards*, a result the converse of that desired would most assuredly be produced, as an oblique surface which smites the air in a downward and *backward* direction (if left to itself) tends to depress the body bearing it. This is proved by the action upon the air of free inclined planes, arranged in the form of a screw.

§ 419. The Wing acts as an Elevator, Propeller, and Sustainer, both during Extension and Flexion.

The wing, as has been explained, is recovered or drawn off the wind principally by the contraction of the elastic ligaments extending between the joints, so that the pinion during flexion enjoys a certain degree of repose. The time occupied in recovering is not lost so long as the wing makes an angle with the horizon and the bird is in motion, it being a matter of indifference whether the wing acts on the air, or the air on the wing, so long as the body bearing the latter is under way ; and this is perhaps the chief reason why the albatross, which is a very heavy bird,[1] can sail about for such incredible periods without apparently moving the wings at all. Captain Hutton thus graphically describes the sailing of this magnificent bird : "The flight of the albatross is truly majestic, as with outstretched, motionless wings he sails over the surface of the sea—now rising high in air, now with a bold sweep, and wings inclined at an angle with the horizon, descending until the tip of the lower one all but touches the crest of the waves as he skims over them." [2]

§ 420. Differences to be noted between Flapping or Rowing Flight and Sailing or Swimming Flight.

Birds of flight may be conveniently divided into four kinds :—

1st. Such as have heavy bodies and short wings driven at a high speed.

2nd. Such as have light bodies and large wings driven more leisurely.

3rd. Such as have heavy bodies and long, narrow wings with a decidedly slow movement ; and

4th. Such as are intermediate with regard to the size of the body, the dimensions of wing, and the energy with which the wing is driven.

They may be subdivided into those which float, skim, and gyrate, those which fly in a straight line, and those which fly irregularly.

[1] The average weight of the albatross, as given by Mr. Gould, is 17 lbs. (*Ibis*, 2nd series, vol. i., 1865, p. 295.)
[2] "On some of the Birds inhabiting the Southern Ocean," by Capt. F. W. Hutton. (*Ibis*, 2nd series, vol. i., 1865, p. 282.)

The pheasant, partridge, grouse, and quail furnish good examples of the heavy-bodied, short-winged birds. In these the wing is rounded and deeply concave. It is, moreover, wielded with immense velocity and power.

The heron, sea-mew, lapwing, and owl supply examples of the second class, where the wing, as compared with the body, is very ample, and where consequently it is moved more leisurely and less energetically. The albatross and pelican furnish instances of the third class, embracing the heavy-bodied, long-winged birds.

The duck, pigeon, crow, and thrush are intermediate, both as regards the size of the wing and the rapidity with which it is made to oscillate.

The albatross, swallow, eagle, and hawk furnish instances of sailing or gliding birds, where the wing is ample, elongated, and more or less pointed, and where advantage is taken of the weight of the body and the shape of the pinion to utilise the air as a supporting medium. In these the pinion acts as a long lever, and is wielded with great precision and power, particularly at the shoulder.[1]

In the short-winged, heavy-bodied birds, which drive their wings at a high speed, the flexion and extension of the wings is a prominent feature of flight. These birds advance with a rapid though steady upward and downward beat of the wings by vigorous, rhythmic, flapping movements. They seldom skim or glide even for short distances.

In the less heavy, ample-winged birds, where the wings are driven leisurely, the flexion and extension of the wings during the up and down strokes, although well marked, are sometimes dispensed with; the birds resorting to sailing or skimming flight.

In the long, narrow-winged, heavy oceanic birds, the flexion and extension of the wings and the up and down strokes are not required, unless when the birds are rising from the water, or when they are suddenly caught by violent adverse winds.

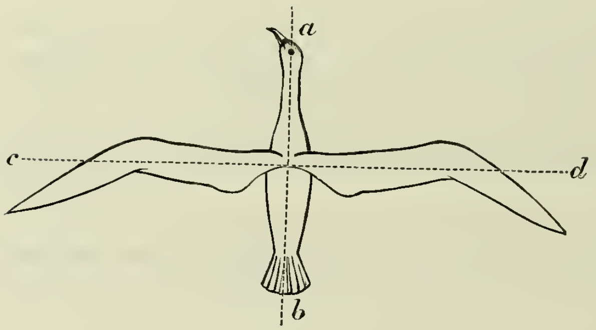


FIG. 528.—The sailing flight of the albatross as depicted by the Author in 1867.

It is not necessary to dilate upon flapping or rowing flight, as the up and down strokes and their connection with the flexion and extension of the wings have been already fully explained. It will suffice to state, that in flapping or rowing flight, flexion and extension and an upward and downward movement of the wings are a necessity, whereas in sailing or skimming flight they are seldom resorted to.

A careful examination of the movements in skimming birds has led me to conclude that by a judicious twisting or screw-like action of the wings at the shoulder, and by an alternate advance and withdrawal of them in an extended state, birds of this order can not only maintain the motion which they secure by a few energetic flappings, but, if necessary, actually increase it, and that without either bending the wings or beating the air.

The twisting or screwing forward and backward action of the pinion referred to in no way interferes, I may remark, with the rotation of the wing on its long axis, the pinion being carried forward and rotated down upon the wind, and retracted or drawn back and rotated off the wind at discretion. As the movements described enable the sailing bird to tilt its body from before backwards, or the reverse, and from side to side or laterally, it may be represented as oscillating on one of two centres, as shown in the subjoined woodcut (Fig. 528), the one corresponding with the long axis of the body (a, b), the other with the long axis of the wings (c, d). Between these two extremes every variety of sailing and gliding motion which is possible in the mariner's compass when set upon gimbals may be performed; so that a skimming or sailing bird may be said to possess perfect command over itself and over the element in which it moves.

Captain Hutton, to whose spirited narrative I have already had occasion to allude, makes the following remarkable statement regarding the albatross: "I have sometimes watched narrowly one of these birds sailing and wheeling about in all directions for more than an hour, without seeing the slightest movement of the wings, and have

[1] *Advantages possessed by Long Pinions.*—The long, narrow wings are most effective as elevators and propellers, from the fact (pointed out by Mr. Wenham) that at high speeds, with very oblique incidences, the supporting effect becomes transferred to the *front edge* of the pinion. It is in this way "that the effective propelling area of the two-bladed screw is tantamount to its entire circle of revolution." A similar principle was announced by Sir George Cayley upwards of fifty years ago. "The stability in this position, arising from the centre of gravity being below the point of suspension, is aided by a remarkable circumstance that experiment alone could point out. *In very acute angles with the current*, it appears that the centre of resistance in the sail does not coincide with the centre of its surface, *but is considerably in front of it.* As the obliquity of the current decreases, these centres approach and coincide, when the current becomes perpendicular to the plane; hence any heel of the machine backwards or forwards removes the centre of support behind or before the point of suspension" (*Nicholson's Journal*, vol. xxv. p. 83). When the speed attained by the bird is *greatly accelerated*, and *the stratum of air passed over in any given time enormously increased*, the support afforded by the air to the inclined planes formed by the wings *is likewise augmented.* This is proved by the rapid flight of skimming or sailing birds when the wings are moved at long intervals and very leisurely. The same principle supports the skater as he rushes impetuously over insecure ice, and the thin, flat stone projected along the surface of still water. The velocity of the movement in either case prevents sinking by not giving the supporting particles time to separate.

PLATE CLXXV

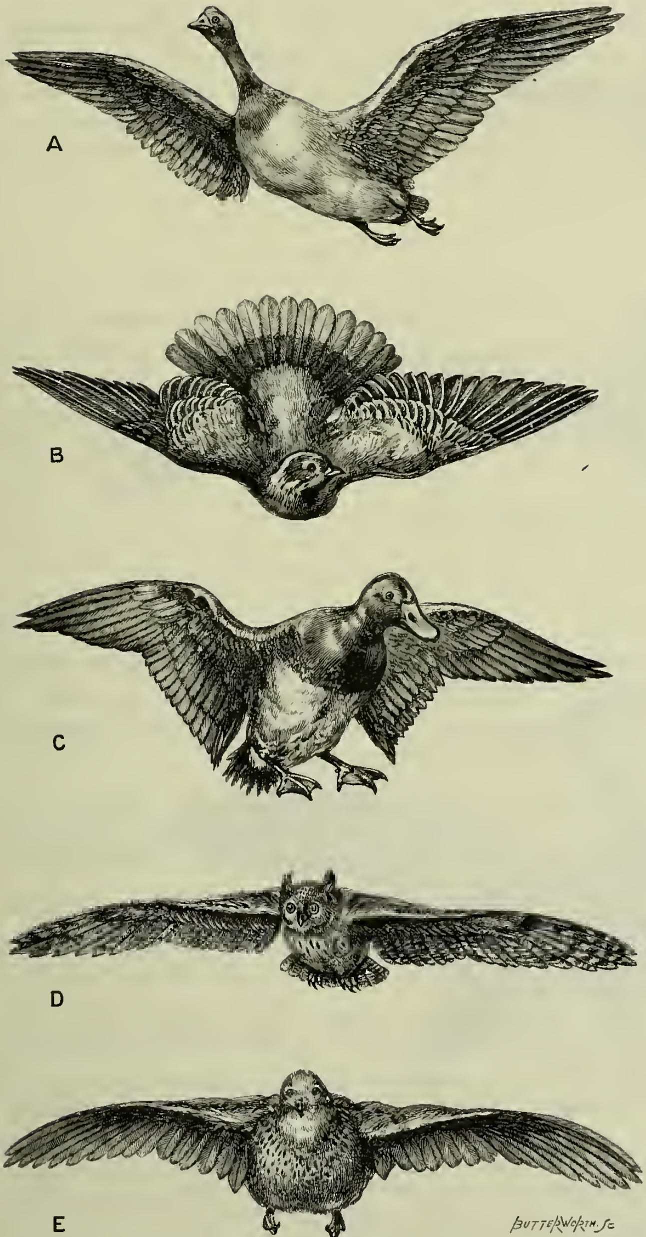


FIG. 1.

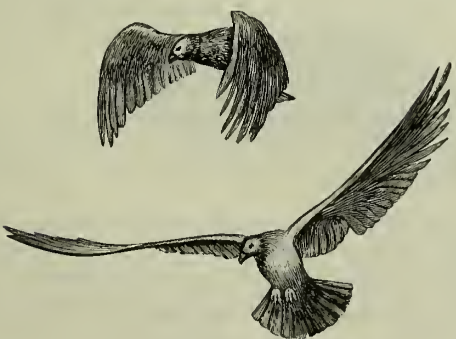


FIG. 2.

FIG. 3.

FIG. 4.

never witnessed anything to equal the ease and grace of this bird as he sweeps past, often within a few yards, every part of his body perfectly motionless except the head and eye, which turn slowly and seem to take notice of everything."[1]

As an antithesis to the apparently lifeless wings of the albatross, the ceaseless activity of those of the humming-bird might be adduced. In those delicate and exquisitely beautiful birds, the wings, according to Mr. Gould, move so rapidly when the bird is poised before an object that it is impossible for the eye to follow each stroke, and a hazy circle of indistinctness on each side of the bird is all that is perceptible. When the humming-bird flies in a horizontal direction, it occasionally proceeds with such velocity as altogether to elude observation. The same is true of the humming-bird moth, as I myself can testify from observation.

§ 421. The Regular and Irregular in Flight.

The coot, diver, duck, and goose fly with great regularity in nearly a straight line and with immense speed; they never skim nor glide, their wings being too small for this purpose. The woodpecker, magpie, fieldfare, and sparrow supply examples of what may be termed the "irregular" in flight. These, as is well known, fly in curves of greater or less magnitude, by giving a few vigorous strokes and then desisting; the effect of which is to project them along a series of parabolic curves. The snipe and woodcock are irregular in another respect, their flight being sudden, jerky, and from side to side.

The more common forms of flight are illustrated at Plates clxxv. and clxxvi.

PLATE CLXXV

Plate clxxv.—Illustrates the flight of birds, some of which flap their wings and do not sail or skim; others which seldom flap their wings and which sail or skim habitually. Fig. 1 (A, B, C, D, E) represents the flight of the goose, pigeon, duck, owl and partridge skimming (from photographs by the Author); Fig. 2, a photograph by E. Muybridge, and Figs. 3 and 4, drawn from nature by C. Berjeau for the present work.

Fig. 1.—A. Flight of the goose. This bird flies by the steady flapping or rowing movement of its wings. The body and wings are tilted upwards and form a considerable angle with the horizon. They present concave kite-surfaces to the nether air—the wings being in a position to strike downwards and forwards. Geese, when in large numbers, fly in one or more V-shaped columns.

B. Pigeon flying downwards. The wings are semi-flexed and the tail spread out; the former to facilitate the descent of the bird, the latter to augment its balancing power.

C. A duck in the act of alighting on the water. The wings are making little short strokes in a downward and forward direction, and the feet and tail are spread out. If the wings were fully extended and making vigorous sweeping movements the bird would be in a position to enable it to rise from, instead of settling on, the water.

D. The common owl hunting. This bird, in virtue of the texture of its primary, secondary, and tertiary feathers, flies noiselessly. Its wings and tail are widely spread out, and with the body form kite-like surfaces; the concavity of the wings being directed downwards. It flies partly by flapping and partly by gliding movements.

E. The red-legged partridge in rapid flight. The wings are fully extended, and presenting their deeply concave surfaces to the nether air. The legs are tucked up to reduce friction in the forward movement. The bird flies mainly by the flapping of its wings, but it occasionally sails for short distances.

Fig. 2.—The flight of the vulture. This is a heavy-bodied, powerfully winged bird, which flies partly by the flapping movements of its wings, and partly by sailing or skimming. In the upper figure, the wings are flexed and the feathers separated and presenting knife-edges to the upper air as in the up stroke. In the lower figure, the wings are fully extended and the tail spread out as happens in sailing flight. The weight of the body is suspended from the wings, and the right wing is twisted upon itself in the direction of its length and converted into an elegant flexible screw. The screw configuration of the right wing is due to the spiral nature of the muscles, bones, and joints of the wing, and to the yielding (under pressure) of its tip and posterior margin. The shape is largely, but not wholly, the result of mechanical pressure; the bird having the power of altering and reversing the double-*f* curves formed by the wing at pleasure. The vulture is one of the most powerful fliers known. It can attain an altitude of several miles, and, when in the upper ether, it sails about for hours together without apparent effort. In this respect it resembles the albatross.

Fig. 3.—The flight of the swallow. This beautiful bird has ample pointed wings and a large, finely-forked tail. It flies chiefly by sailing or gliding movements; the flapping or rowing movements of the wings being employed as auxiliary to the gliding movements. The flight of the swallow and of the swift is to be regarded as the poetry of motion, alike because of its rapidity, its sudden wheeling in dainty curves in any and every direction, and its perfect smoothness and exquisite grace. The swallow and swift are equal to capturing all kinds of insects on the wing—the dragon-fly excepted.

Fig. 4.—The flight of the swift. This bird, as its name indicates, is, on the whole, the fleetest of the small birds. It is provided with long, narrow, pointed, scythe-like wings, a large forked tail, and a beautiful fish-like body, which enable it to sweep through the air with incredible velocity. Its flight is a continuation of flapping and gliding movements—the two movements blending in such a way and so rapidly as to make it next to impossible to separate them. To watch a swift flying, and hear it scream as it flies, is one of the great object-lessons of nature. It is a veritable embodiment of power and speed at their best.

[1] "On some of the Birds inhabiting the Southern Ocean." (*Ibis*, 2nd series, vol. i., 1865.)

PLATE CLXXVI

FIG. 1.

FIG. 2.

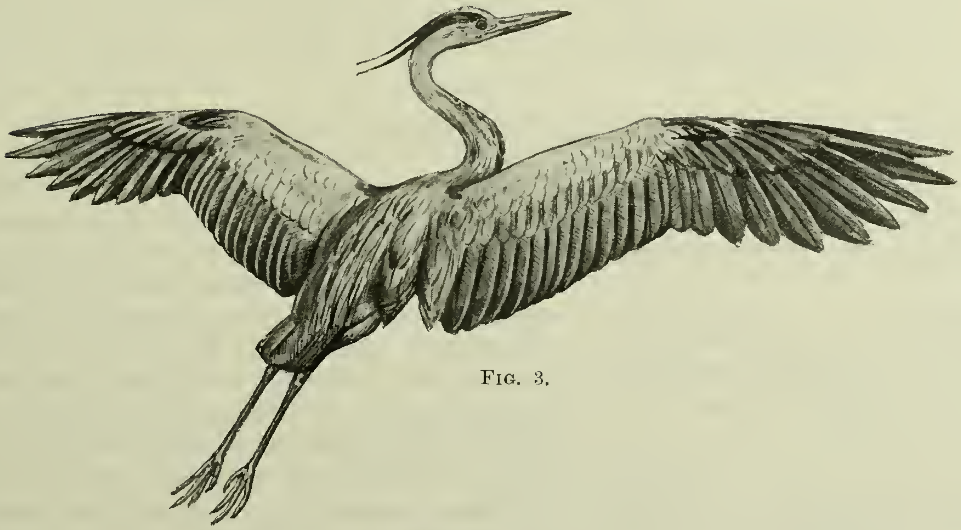


FIG. 3.

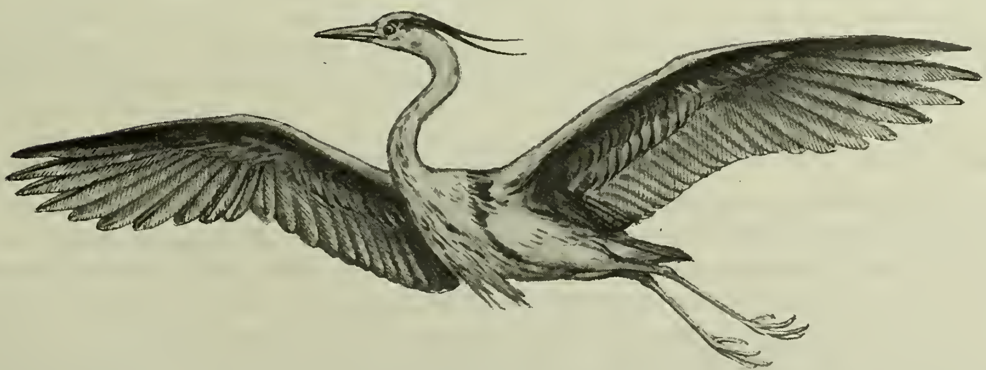


FIG. 4.

PLATE CLXXVI

Plate clxxvi.—Illustrates flapping or rowing flight as seen in the diver and heron: also sailing flight as witnessed in the sea-gull. Figs. 1 and 2 are from photographs by the Author. Figs. 3 and 4 are drawn from nature by C. Berjeau for the present work.

Fig. 1.—The common diver. This bird is remarkable for its small wings and the comparatively very large size of its body. Its body weighs 2 lbs., the same as that of the body of the sea-gull in Fig. 2. In comparing the wings of the diver with those of the sea-gull they are seen to be extremely small—so small, indeed, as to make it difficult to understand how they can elevate and carry forward the heavy body to which they are attached. They are only about a quarter the size of the wings of a gull of the same weight. The explanation is to be found in the enormous speed at which they are driven. It is a case of diminutive wings, heavy body, excessive power, and high speed, as against the very much larger wings, comparatively lighter, weaker body, and slow speed of the sea-gull. The diver flies by sudden, energetic, quick movements; the wings being alternately flexed and elevated and extended and depressed. It cannot sail or skim, and when it alights in the water it does so with a splash.

Fig. 2.—The large grey gull. This bird is provided with very large, powerful wings and a comparatively light body which weighs 2 lbs. It flies partly by the leisurely flapping of its wings and partly by sailing, which is accomplished by holding the wings in the extended position with their concave surfaces directed downwards. When the concave surfaces are so disposed, they act after the manner of parachutes, and when tilted, as they generally are in flight, to make an angle with the horizon, they act as kites which at once sustain and glide.

Fig. 3.—The flight of the heron, dorsal view. This bird is furnished with unusually large wings considering the size of its body. The primary, secondary, and tertiary feathers of the wings stand boldly out, especially the primaries, which are slightly separated towards the tips of the wings. The right wing is fully extended; the left one appearing slightly flexed from being fore-shortened. The bird is armed with a large, powerful beak, and has a long neck, an elongated body, and exceptionally long legs for wading. The long neck and legs contribute to the perfect balance of the body in flight. The flight of the heron is peculiar, in that it is somewhat laboured and very slow. The wings make exactly sixty down and sixty up strokes per minute, that is, one down and one up stroke per second. I have had frequent opportunities of verifying this statement in heronries and other places where I could make observations without being seen. The heron was the favourite quarry in the days of falconry, and it is the most picturesque bird in the British landscape. It flies with slow, almost solemn movements, in which its wings are elevated and depressed and flexed and extended with great regularity.

Fig. 4.—The flight of the heron—ventral view. The account given in Fig. 3 is equally applicable to Fig. 4. It is only necessary to state that in the present figure the under concave surface of the wings and the body of the bird make an upward angle with the horizon and act as inclined planes or kites during flight. The wings, being deeply concave on their under surfaces, also exert a parachute action. The heron is capable of very long and even very high flights; the distances covered by it in going to and from its fishing grounds being, in some instances, very great.

THE WING ACTS AS A TRUE KITE BOTH DURING THE DOWN AND UP STROKES

If, as I have endeavoured to explain, the wing, even when elevated and depressed in a strictly vertical direction, inevitably and invariably darts forward, it follows as a consequence that the wing, as already partly explained, flies forward as a true kite, both during the down and up strokes, as shown at *c, d, e, f, g, h, i, j, k, l, m* of Fig. 529; and that its under concave or biting surface, in virtue of the forward travel communicated to it by the body in motion, is closely applied to the air, both during its ascent and descent—a fact hitherto overlooked, but one of considerable importance, as showing how the wing furnishes a persistent buoyancy, alike when it rises and falls.

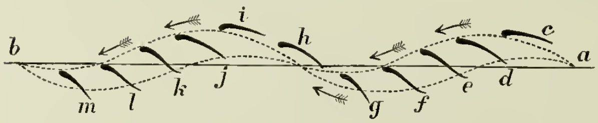


Fig. 529.

In Fig. 529 the greater impulse communicated during the down stroke is indicated by the double dotted lines. The angle made by the wing with the horizon (*a, b*) is constantly varying, as a comparison of *c* with *d*, *d* with *e*, *e* with *f*, *f* with *g*, *g* with *h*, and *h* with *i* will show; these letters having reference to supposed transverse section of the wing. This figure also shows that the *convex* or non-biting surface of the wing is always directed upwards, so as to avoid unnecessary resistance on the part of the air to the wing during its ascent; whereas the *concave* or biting surface is always directed downwards, so as to enable the wing to contend successfully with gravity.

§ 422. Analogy between the Wing and a Boy's Kite—Points of Difference to be Noted.

I first directed attention to the kite action of the wing in 1867 in the following terms: The wing strikes the air precisely as a boy's kite would if it were jerked by its string, the only difference being that the kite is *pulled forwards* upon the wind by its string and the hand; whereas in the insect, bird, and bat, the wing is *pushed forwards* on the wind by the weight of the body and the power residing in the pinion itself.[1] When the wing of the

[1] Since I gave the above explanation of the action of the wing (*Proceedings of the Royal Institution of Great Britain*, March 1867), Mr. Reda St. Martin has constructed a model with a view to testing the efficacy of this principle in artificial flight. It consists of an ordinary kite with two screws situated near its upper and central part, the axes of which are at right angles to the plane of the kite and the plane of progression. The screws are made to revolve with their blades turned in a downward direction, the idea being to force the kite down upon the wind from behind. This result would, however, be secured by the inertia of the machine, independently of the screws.

bird descends it makes a variable angle with the body in addition to the angles which it makes with the horizon, so that in this direction also it acts as an inclined plane and levers the body upwards. When, moreover, it is being recovered or flexed preparatory to making a second down stroke, it is drawn from below upwards and from before backwards, the angles which are made by the curtain of the wing with the horizon during extension being gradually diminished, as indicated at Fig. 529.

The natural kite formed by the wing differs from the artificial kite in this, that the former is capable of being moved in all its parts, and is more or less flexible and elastic, the latter being comparatively rigid. The flexibility and elasticity of the kite formed by the natural wing are rendered necessary by the fact that the wing is articulated or hinged at its root; its different parts travelling at various degrees of speed in proportion as they are removed from the axis of rotation. Thus the tip of the wing travels through a much greater space in a given time than a portion nearer the root. If the wing were not flexible and elastic, it would be impossible to reverse it at the end of the up and down strokes, so as to produce a continuous vibration. The wing is also practically hinged along its interior margin, so that the posterior margin of the wing travels through a greater space in a given time than a portion nearer the anterior margin. The compound rotation of the wing is greatly facilitated by the wing being flexible and elastic. This causes the pinion to twist upon its long axis during its vibration, as already stated. The twisting is partly a vital, and partly a mechanical act; that is, it is occasioned in part by the action of the muscles, in part by the reaction of the air, and in part by the greater momentum acquired by the tip and posterior margin of the wing, as compared with the root and anterior margin; the speed acquired by the tip and posterior margin causing them to reverse always subsequently to the root and anterior margin, which has the effect of throwing the anterior and posterior margins of the wing into figure-of-8 curves. It is in this way that the posterior margin of the outer portion of the wing is made to incline forwards at the end of the down stroke, when the anterior margin is inclined backwards; the posterior margin of the outer portion of the wing being made to incline backwards at the end of the up stroke, when a corresponding portion of the anterior margin is inclined forwards.

§ 423. The Angles formed by the Wing with the Horizon during its Vibrations.

Not the least interesting feature of the compound rotation of the wing—of the varying degrees of speed attained by its different parts, and of the twisting or plaiting of the posterior margin around the anterior—is the great variety of kite-like surfaces developed upon its dorsal and ventral aspects. Thus the tip of the wing forms a kite which is inclined upwards, forwards, and outwards, while the root forms a kite which is inclined upwards, forwards, and inwards. The angles made by the tip and outer portions of the wing with the horizon are less than those made by the root and inner portions. The angle of inclination peculiar to any portion of the wing increases as the speed of the said portion decreases, and *vice versâ*. The wing is consequently mechanically perfect; the angles made by its several parts with the horizon being accurately adjusted to the speed attained by its different portions during its travel to and fro. From this it follows that the air set in motion by one part of the wing is seized upon and utilised by another; the inner and anterior portions of the wing supplying, as it were, currents for the outer and posterior portions. This results from the wing always forcing the air outwards and backwards. These statements admit of direct proof, and I have frequently satisfied myself of their exactitude by experiments made with natural and artificial wings.

In the bird and bat, the twisting of the wing upon its long axis is more of a vital and less of a mechanical act than in the insect; the muscles which regulate the vibration of the pinion in the former (bird and bat) extending quite to the tip of the wing.

The kite action of the wings in the sea-gull is well seen in Fig. 530. In this figure I have affixed two cords (*a*, *b*), one to the under concave surface of each wing (*c*, *d*) in imitation of the string which keeps the boy's kite in position. The cords tend to pull the body of the bird (*e*) downwards and forwards, but the wings tend to raise it upwards and forwards (*f*, *g*); the actual line of flight being intermediate between the two. The body of the bird is to the wings what the string and the hand holding it are to the boy's kite.

The peculiarities of flapping and sailing flight in the sea-gull, and the flexion, semi-flexion, and extension of the wings are illustrated at Figs. 531 and 532. In Fig. 531, which represents four phases (A, B, C, D) of the flight of the sea-gull, I show the extent to which the wings are flexed in rowing flight, the extent to which they are extended in sailing flight, and the double-*f* curves made by the anterior and posterior margins of the wings in partial flexion: also the extent to which the posterior margins of the outer halves of the wings may be elevated above corresponding parts of the anterior margins during the down stroke in certain phases of flight.

At A, where the flapping or rowing flight of the sea-gull is represented, the right wing (*a*, *b*, *c*, *d*) is flexed at the wrist-joint (*b*); the outer half of the wing (*d*) moving outwards in extension and inwards in flexion—the tip of the wing describing an oblique oval trajectory in the air.

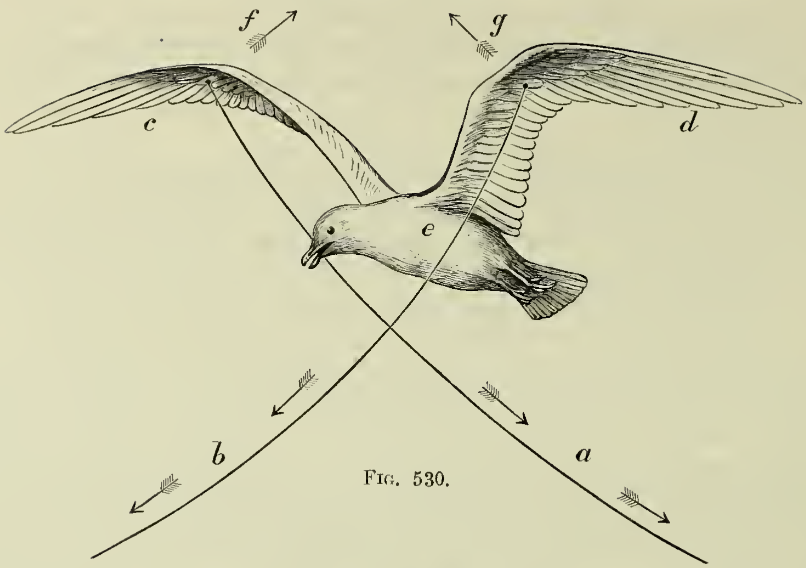


Fig. 530.

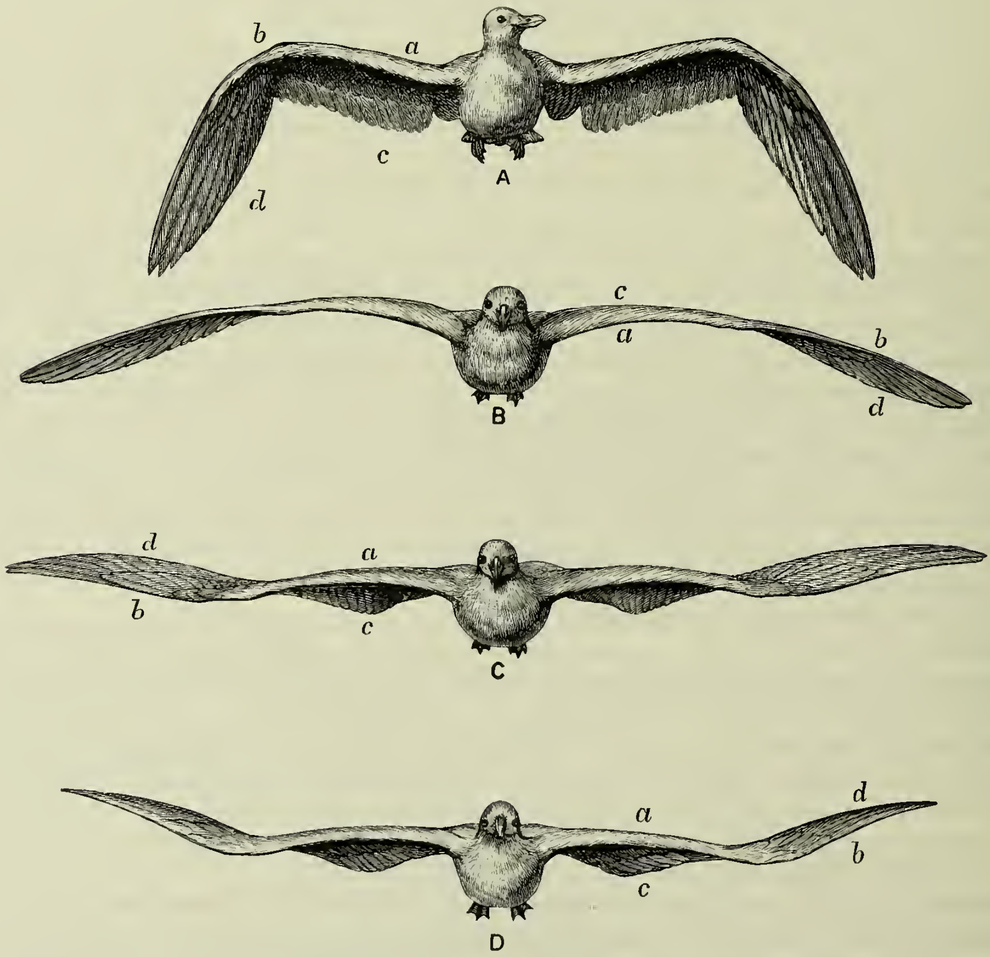


Fig. 531.

Fig. 532.

At B, C, and D of Fig. 531, the wings form graceful flexible screws. At B the wings are fully extended and thrown into two beautiful arches as in sailing flight. In this case, the convex surface at the root of the wing is directed upwards, the concave surface being directed downwards; the anterior (*a*, *b*) and posterior (*c*, *d*) margins of the wings being arranged in different planes and forming double-*f* figure-of-8 curves; the wings being twisted in the direction of their length screw-fashion.

At C, the wings are partly flexed and form mobile screws—the screws being the reverse of those seen at B. Thus the concave surfaces of the wings at the root are directed downwards (*a*, *c*); the convex ones at the tips of the wings being directed upwards (*b*, *d*). The same thing happens in complete flexion of the wing, as shown at A of Fig. 532.

At Fig. 532 (A, B, C) the double-*f* curves made by the anterior (*c*, *a*, *b*) and posterior (*d*, *e*, *f*) margins of the wing in flexion, semi-flexion, and extension are delineated. The curves formed by the margins in flexion (A) are the opposite of those formed in extension (C). The wings in flexion and extension are continually reversing their curves, and so produce a cross pulsation of the air in flight.

FIG. 530.—Shows the kite action of the wings in the flight of the sea-gull. *a*, *b*, Cords attached to the under concave surfaces of the wings (*c*, *d*)—these surfaces being inclined upwards (kite-fashion), and making various angles with the horizon. The cords, as in the boy's kite, tend to pull the wings and the body of the bird (*e*) downwards and forwards. The wings, on the other hand, tend to raise the body in an upward and forward direction (*f*, *g*)—the line of flight being the resultant of the two opposing forces (the Author, 1867).

FIG. 531.—A. Shows the degree of flexion which occurs in the wings of the sea-gull in flapping or rowing flight. *a*, *b*, Thick, semi-rigid, anterior margin of right wing; *c*, *d*, thin, flexible, highly elastic posterior margin.

B. Represents the sailing flight of the sea-gull, where the wings are fully extended and held at right angles to the body and on a level with it. The under surfaces of the wings form two beautiful arches, which have a combined parachute and kite action. *a*, *b*, Semi-rigid anterior margin of left wing; *c*, *d*, thin, flexible, highly elastic, posterior margin. The margins are arranged in two different planes, and convert the wing into a mobile helix or screw.

C and D. The wings of the sea-gull partially flexed, as happens when the bird is flying against a light breeze. In this case also the wings form mobile helices or screws. They are the reverse of those seen at B. At B, the inner half of the wing has its convex surface directed upwards; the outer concave surface being directed downwards. At C and D, these conditions are reversed. *a*, *b*, Semi-rigid anterior margin of left wing; *c*, *d*, thin, flexible, highly elastic posterior margin (the Author, 1867).

FIG. 532.—The wing of the sea-gull as seen in flexion, semi-extension, and extension.

A. The wing in flexion viewed from behind. The anterior (*d*, *e*, *f*) and posterior (*c*, *a*, *b*) margins of the wings are arranged in different planes, and convert the organ into a mobile helix or screw. The margins form opposite, complemental, double-*f* curves, and present a figure-of-8 outline. The curves are the opposite of those seen in extension (D).

B. The wing in semi-extension. In this case the curves on the posterior margin (*b*, *c*) are obliterated; the wing being in the act of reversing or changing from the flexed to the extended state. *d*, *e*, *f*, Anterior margin of wing; *b*, *c*, posterior margin.

C. The wing in the extended state. In this figure the curves made by the anterior and posterior margins are the reverse of those seen at A (flexion). *d*, *e*, *f*, Anterior margin of wing; *c*, *a*, *b*, double-*f* curve made by posterior margin of wing (the Author, 1867).

§ 424. The Margins of the Wing thrown into Opposite Curves during Extension and Flexion.

The anterior or thick margin of the wing, and the posterior or thin one, form different curves, similar in all respects to those made by the body of the fish in swimming. These curves may, for the sake of clearness, be divided into axillary and distal curves, the former occurring towards the root of the wing, the latter towards its extremity. The curves (axillary and distal) found on the anterior margin of the wing are always the converse of those met with on the posterior margin; that is, if the convexity of the anterior axillary curve be directed downwards, that of the posterior axillary curve is directed upwards, and so of the anterior and posterior distal curves. The two curves (axillary and distal), occurring on the anterior margin of the wing, are likewise opposite and complemental, the convexity of the axillary curve being always directed downwards, when the convexity of the distal one is directed upwards, and *vice versâ*. The same holds true of the axillary and distal curves occurring on the posterior margin of the wing. The anterior axillary and distal curves completely reverse themselves during the acts of extension and flexion, and so of the posterior axillary and distal curves (Fig. 532). This antagonism in the axillary and distal curves found on the anterior and posterior margins of the wing is referable in the bird and bat to changes induced in the bones of the wing in the acts of flexion and extension. In the insect it is due to spiral torsion occurring at the root of the wing, and to the reaction of the air.

§ 425. The Tip of the Bird's and Bat's Wing describes an Ellipse.

The movements at the wrist of the wing are always the converse of those occurring at the elbow-joint. Thus in the bird, during extension, the elbow and bones of the forearm are elevated, and describe one side of an ellipse,

while the wrist and bones of the hand are depressed, and describe the side of another and opposite ellipse. These movements are reversed during flexion, the elbow being depressed and carried backwards, while the wrist is elevated and carried forwards (Fig. 533).

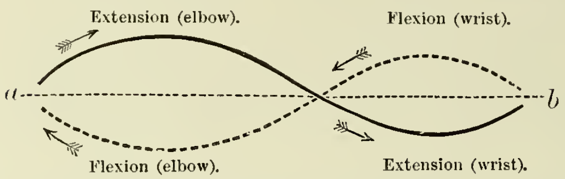


Fig. 533.—a, b, Line along which the wing travels during extension and flexion. The body of the fish in swimming describes similar curves to those described by the wing in flying (the Author, 1867).

§ 426. The Wing capable of Change of Form in all its Parts.

From this description it follows that when the different portions of the anterior margin are elevated, corresponding portions of the posterior margin are depressed; the different parts of the wing moving in opposite directions and playing, as it were, at cross purposes for a common good; the object being to rotate or screw the wing down upon the wind at a gradually increasing angle during extension, and to rotate it in an opposite direction and withdraw it at a grad ally decreasing angle during flexion. It also happens that the axillary and distal curves are co-ordinated and bite alternately, the distal curve posteriorly seizing the air in extreme extension with its concave surface while the axillary curve relieves itself by presenting its convex surface; the axillary curve, on the other hand, biting during flexion with its concave surface while the distal one relieves itself by presenting its convex one. The wing may therefore be regarded as exercising a fourfold function, the pinion in the bird and bat being made to move from within outwards, and from above downwards, in the down stroke, during extension; and from without inwards, and from below upwards, in the up stroke, during flexion.

§ 427. The Wing when made to Vibrate produces a Cross Pulsation.

The oscillation of the wing on two separate axes—the one running parallel with the body of the bird, the other at right angles to it—is well worthy of attention, as showing that the wing attacks the air on which it operates in every direction, and at almost the same moment, namely, from within outwards, and from above downwards, during the down stroke; and from without inwards, and from below upwards, during the up stroke. As a corollary to the foregoing, the wing may be said to agitate the air in two principal directions, namely, from within outwards and downwards, or the converse; and from behind forwards, or the converse; the agitation in question producing two powerful pulsations, a vertical and a horizontal. The wing when it ascends and descends produces artificial currents which increase its elevating and propelling power. The power of the wing is further augmented by similar currents developed during its extension and flexion. The movement of one part of the wing contributes to the movement of every other part in continuous and uninterrupted succession. As the curves of the wing glide into each other when the wing is in motion, so the one pulsation merges into the other by a series of intermediate and lesser pulsations.

The vertical and horizontal pulsations occasioned by the wing in action may be fitly represented by wave-tracks running at right angles to each other, the vertical wave-track being the more distinct.

§ 428. Compound Rotation of the Wing.

To work the tip and posterior margin of the wing independently and yet simultaneously, two axes are necessary, one axis (the short) corresponding to the root of the wing and running across it; the second (the long) corresponding to the anterior margin of the wing, and running in the direction of its length. The long and short axes render the movements of the wing eccentric in character. In the wing of the bird the movements of the primary or rowing feathers are also eccentric, the shaft of each feather being placed nearer the anterior than the posterior margin; an arrangement which enables the feathers to open up and separate during flexion and the up stroke, and approximate and close during extension and the down one.

These points are illustrated at Fig. 513, p. 1243, where *a*, *b* represents the short axis (root of wing) with a radius *e*, *f*; *c*, *d* representing the long axis (anterior margin of wing) with a radius *g*, *p*.

Fig. 513 also shows that, in the wing of the bird, the individual primary and secondary feathers have each what is equivalent to a long and a short axis. Thus the primary and secondary feathers, marked *h*, *i*, *j*, *k*, *l*, are capable of rotating on their long axes (*r*, *s*), and upon their short axes (*m*, *n*). The feathers rotate upon their long axes in a direction from below upwards during the down stroke, to make the wing impervious to air; and from above downwards during the up stroke, to enable the air to pass between the feathers. The primary

and secondary feathers have thus a distinctly valvular action.[1] The feathers rotate upon their short axes (m, n) during the descent and ascent of the wing, the tip of the feathers rising slightly during the descent of the pinion, and falling during its ascent. The same movement virtually takes place in the posterior margin of the wing of the insect and bat.

§ 429. The Wing Oscillates unequally with Reference to a Given Line.

The wing, during its vibration, descends further below the body than it rises above it. This is necessary for *elevating purposes.* In like manner, the posterior margin of the wing (whatever the position of the organ) descends further below the anterior margin than it ascends above it. This is requisite for *elevating and propelling purposes ;* the under concave surface of the wing being always presented at a certain upward angle to the horizon, and acting as a true kite. If the wing oscillated equally above and beneath the body, and if the posterior margin of the wing was made to vibrate equally above and below the line formed by the anterior margin, much of its elevating and propelling power would be sacrificed. The tail of the fish oscillates on either side of a given line, but it is otherwise with the wing of a flying animal. The fish is of nearly the same specific gravity as the water, so that the tail may be said only to propel. The flying animal, on the other hand, is very much heavier than the air, so that the wing requires both to propel and *elevate.* The wing, to be effective as an *elevating organ,* must consequently be made to vibrate rather below than above the shoulder-joint ; at all events, the intensity of the vibration should occur rather below that point. In making this statement, it is necessary to bear in mind that the centre of gravity in birds is suspended and *ever varying,* the body rising and falling in a series of curves as the wings ascend and descend.

To *elevate* and *propel,* the posterior margin of the wing must rotate round the anterior one ; the posterior margin being, as a rule, always on a lower level than the anterior one. By the oblique and more vigorous play of the wings *under* rather than *above* the body, each wing expends its entire energy in pushing the body *upwards* and *forwards.* It is necessary that the wings descend further than they ascend ; that the wings be *convex* on their upper surfaces, and *concave* on their under ones ; and that the concave or biting surfaces be brought more violently in contact with the air during the down stroke than the convex ones during the up stroke. The greater range of the wing below than above the body, and of the posterior margin below than above a given line, may be readily made out by watching the flight of the larger birds, but it is also well seen in the upward flight of the lark. In the hovering of the kestrel over its quarry, and the hovering of the gull over garbage which it is about to pick up, the wings play above and on a level with the body rather than below it ; but these are exceptional movements for special purposes, and as they are only continued for a few seconds at a time, they do not affect the accuracy of the general statement.

§ 430. The Flight of the Sea-Gull as witnessed on the West Coast of Scotland.

In my many autumn yachting and steamboat excursions in the Firth of Clyde, I enjoyed the most favourable opportunities of exhaustively studying the flight of the sea-gull and many other aquatic birds. The sea-gulls were my special study for several years, and Figs. 530, 531, and 532 are the outcome of a large number of observations. These figures I drew and described on board ship from the living birds, frequently seen at very short distances. When the birds were not in the vicinity of the vessel I happened to be in, I employed powerful field-glasses and with very satisfactory results. The deck of one of the beautiful swift Clyde steamers affords unusual facilities for such investigations. The birds are habitually fed from all the Clyde steamers, and are wonderfully tame. As a consequence they fly right overhead, on the surface of the water, in front of, behind, and on either side of the vessels ; in many cases, not more than six or eight yards from the spectator. They also swoop down to pick up garbage and other food, settle on the water for short intervals, and again take wing and make up leeway. They are seen flying towards and away from the vessel and circling about it in all directions. There is no possible position the birds do not assume under the circumstances, and the feats of wingmanship they display are simply marvellous.

I transcribe some of my notes on the flight of the sea-gull taken on various occasions under the conditions described above. The following are a few of the points made out :—

1. The wings have a kite action.
2. In flapping or rowing flight, the wings make extensive excursions above and below the bird ; the wings being fully extended at the beginning of the down stroke, and fully flexed at the beginning of the up stroke.
3. Flexion is effected chiefly at the wrist-joint, and is most evident when the bird is settling upon or leaving the water. In this case, the wing strikes very decidedly downwards and *forwards* during the down stroke.

[1] The degree of valvular action varies according to circumstances.

4. When the bird is flying leisurely against a light breeze, the degree of flexion and the extent of the down and up strokes are reduced by about a half. Under these circumstances the wrist movement of the wing is very perceptible. The wing appears to be divided into two portions, the inner portion being held at right angles to the body in a fixed position—the outer portion, bearing the primary feathers, performing a winnowing, fanning movement, characterised by short strokes, partial flexion and extension, and by the tip of the wing describing an oblique oval trajectory in space.

5. The inner half of the wing in leisurely flight acts as a sustainer or parachute ; the outer half acting as an elevator and propeller.

6. When a stiffish breeze is blowing and the bird is flying against it, the area of the wing is, as a rule, considerably diminished. In this case, the upper convex surface of the outer half of the wing is directed upwards, this portion of the wing being ever and anon everted. The eversion is due partly to wind pressure, and partly to a voluntary movement of the several parts of the wing at the wrist ; the bird regulating the amount of eversion and movement generally with the greatest precision and skill.

7. The wing, and the primary, secondary, and tertiary feathers of the wing, are visibly under control ; the two together forming a mobile, elastic, reciprocating screw, the flanges, curves, and angles of which are constantly changing.

8. The wing in flapping or rowing flight is more or less lax, and is wielded loosely but designedly, and of set purpose, to achieve certain results. Its movements are never haphazard or casual. On the contrary, they are severely under control ; each joint and rowing feather being dominated by the nerves of the wing and the will of the bird. This becomes more and more apparent according as the observations are repeated and become more exact.

9. The wings in sailing or skimming flight are fully extended, and form two beautiful arches—one on either side of the bird. In this case the wings are stiffened and are held at right angles to the long axis of the body, and on a level with it. They form semi-rigid screws ; the inner halves and convex surfaces of the wings being directed upwards and forwards, the outer and concave surfaces being directed downwards and backwards. The anterior and posterior margins and curves of the wings are arranged in different planes, and confer on them a distinctly screw configuration.

10. In sailing flight, the breeze, or air in motion, does the chief part of the work ; the bird having only to regulate the position of the wings and the angles made by them with the horizon. This it does principally from the shoulder-joints—the other joints being more or less fixed. In sailing flight the concave or under surfaces of the wings act as true kites—the bird utilising its weight and arranging all the details. Sailing flight is no more haphazard than flapping flight. Both are regulated and supervised in a way not even remotely recognised by the ordinary observer.

11. In the movements of flexion and extension the anterior and posterior margins of the wing are thrown into graceful, complementary, double-*f* curves ; these curves being continually reversed, and giving rise to a cross pulsation of the air in flight. In flexion, the curves are the opposite of those which obtain in extension.

§ 431. Analysis of the Movements of Extension and Flexion in the Wing of the Gannet.

The changes which the wing undergoes in extension and flexion are seen to great advantage in the gannet (Plate clxxii., Fig. 1, p. 1241).

The pinion of this bird is remarkable for its great length and strength, as compared with its breadth, and for the general elegance of its shape. It is especially interesting from the fact that the wing movements can be more readily and satisfactorily analysed by its aid than by that of any other British wing with which I am acquainted. The following account, taken from a perfectly fresh specimen, may prove interesting.

The joints of the gannet's wing, particularly the shoulder-joint, admit of very free movements. When the wing is slightly flexed the under surface of the posterior margin of the pinion can be rotated downwards and forwards until it makes a right angle with the horizon—the greatest angle which it makes in extension amounting to something like 45°. In flexion, the elbow, wrist, and metacarpal joints admit of a great variety of movement, the forearm moving on the arm, and the hand upon the forearm in an oblique spiral direction from above downwards and from below upwards. In flexion the whole pinion is flaccid, and the primary, secondary, and tertiary feathers separated and thrown out of position. The forearm is folded upon the arm in nearly the same plane ; the secondary and tertiary feathers being inclined slightly upwards and forwards, so that they form an inclined surface with the horizon.

The hand rotates upon the wrist as upon a spiral hinge, the tip of the wing, as it darts out and in, describing the segment of a circle. The hand is folded upon the forearm in such a manner that the anterior margin of the

tip of the wing ascends, while the posterior margin descends. The hand and tip of the wing during flexion form an inclined surface with the horizon—the surface being directed *outwards* and *upwards*. The tip of the wing in flexion acts as a true kite from *below upwards* and from *within outwards*.[1] The flexed wing of the gannet displays four different inclined surfaces, two directed upwards and *outwards*, and two directed upwards and *inwards*. These surfaces when the wing is moving are ever varying, and cause the different portions of the pinion to act like so many kites. Thus, during extension, two portions of the wing fly outwards and upwards ; two other portions flying upwards and inwards during flexion. As the two portions of the wing which act during extension draw a current of air after them, on which the other two portions operate during flexion, it follows that one part of the wing, whatever its position, makes an air current on which another portion inevitably acts. The wing, I may add, produces an artificial air current during the up stroke on which it operates during the down stroke and *vice versâ*. When the gannet's wing is extended and flexed by the aid of the hand, it shows the screwing and unscrewing action of the pinion to perfection ; the dorsal and ventral surfaces of the wing oscillating on either side of a given line—the dorsal surface appearing above the line in flexion and the ventral surface under the line in extension.

§ 432. The Angles of Inclination which the Under Surfaces of the Gannet's Wing make with the Horizon in Extension and Flexion vary.

When the wing of the gannet is extended the angle which its under surface makes with the horizon, especially the portion opposite the elbow-joint, is much greater than one would anticipate—indeed, it is little short of 45°. The tip of the wing does not, however, make an angle of more than 25° or 30°. This is a most interesting point, as it shows that the different portions of the wing in extension make different angles with the horizon—that made by the tip of the wing being the least, and that made by the root of the wing the greatest. The inclined surfaces are no doubt adapted to suit the speed attained by the several parts of the wing, and to produce a uniform result as far as buoyancy is concerned. Thus the wing acts with a gradually decreasing angle from the root towards the tip—the speed of the wing increasing in the direction of its extremity. The wing acts on strictly mechanical principles ; a small angle travelling at a high speed supplying the same amount of buoying power as a greater angle moving at a lower speed. Indeed, on making a careful examination of the gannet's wing, I have had no difficulty in determining that the different parts of the wing not only make various angles of inclination with the horizon in an antero-posterior direction at every stage of extension and flexion during the down and up strokes, but that they also make various angles of inclination with the horizon in a direction from within outwards. In other words, I find that in extension and flexion the wing attacks the air from behind forwards and from within outwards at one and the same instant—the different parts of the pinion tacking upon the air kite fashion, in several directions at the same time. The wing attacks the air (at various angles of inclination) from within outwards, and from behind forwards, and from without inwards and from before backwards. The various angles of inclination made by the wing with the horizon from within outwards and the reverse, and from behind forwards and the reverse, are all necessary to produce a perfect buoyancy.

When the wing of the gannet is fully extended it is also rendered more or less rigid. The joints, however, even the metacarpal ones, are free to move, which shows that the wing, to be effective during the down stroke, must be thoroughly under the control of the muscles and elastic ligaments. This is all the more necessary, as the roots of the primary and secondary feathers are inclined to move in an upward direction as the wing descends, and require to be restrained.

After carefully analysing the movements of the gannet's wing in the dead bird, I felt the necessity of studying the same movements in the living one. I therefore made an excursion to the Bass Rock (Firth of Forth, Scotland) for this purpose, in July 1870. It was breeding season, and the birds were in myriads, and so tame that they wheeled around and above me at distances, in some cases, not exceeding six to eight yards. The gannets which were hatching permitted me to approach within a yard of them, and required to be driven from their nests by the aid of a stick. I had, therefore, every facility for analysing the flight of this the most cherished and beautiful of the British birds. Before proceeding to describe the results of the expedition in question I may state, briefly, the measurement, weight, &c., of the gannet, the movements of the wings of which I have just recorded. For the sake of comparison I will also give the weight and measurements of a heron—this bird differing widely from the gannet in the configuration of its wings (Plate clxxii., Fig. 3, p. 1241).

[1] The same happens in the wings of all birds, and in the wing of the insect and bat. The outward and upward inclination of the tip of the wing is well seen in the beetle. This portion of the wing acts as a true kite, when the wing is being extended or thrust away from the body towards the termination of the up stroke. The under surface of the tip of the wing consequently contributes to flight during the up stroke

MEASUREMENTS, WEIGHTS, &c., OF GANNET AND HERON

The following details of weight, measurement, &c., of the gannet were obtained from an adult specimen which I dissected during the winter of 1869. Entire weight, 7 lbs. (minus 3 ounces); length of body from tip of bill to tip of tail, 3 feet 4 inches; head and neck, 1 foot 3 inches; tail, 12 inches; trunk, 13 inches; girth of trunk, 18 inches; expanse of wing from tip to tip across the body, 6 feet; widest portion of wing across the primary feathers, 6 inches; across the secondaries, 7 inches; across the tertiaries, 8 inches. The heron, a specimen of which I dissected at the same time, gave a very different result, as the subjoined particulars will show.

Weight of body, 3 lbs. 3 ounces; length of body from tip of bill to tip of tail, 3 feet 4 inches; head and neck, 2 feet; tail, 7 inches; trunk, 9 inches; girth of body, 12 inches; expanse of wing from tip to tip across the body, 5 feet 9 inches; widest portion of wing across primary and tertiary feathers, 11 inches; across secondary feathers, 12 inches.

The gannet has, consequently, less than half of the wing area of the heron. The gannet's wing is, however, a long, narrow wing (that of the heron is broad), extended transversely across the body in the direction of its length; and this is found to be the most powerful form of wing—the wings of the albatross, which measure 14 feet from tip to tip (and only 1 foot across), elevating 18 lbs. without difficulty. If the wing of the gannet has a small superficial area as compared with the wing of the heron, it follows that the gannet's wing must be driven at a much greater speed; and this is actually what happens. The heron's wing, as I have stated elsewhere, makes 60 down and 60 up strokes every minute; whereas the wing of the gannet, when the bird is flying in a straight line to or from its fishing ground, makes close upon 150 up and 150 down strokes during the same period. The wings of the divers and other short-winged, heavy-bodied birds are urged at a much higher speed, so that a comparatively small wing can be made to elevate a comparatively heavy body, if the speed with which the wing is driven only be increased sufficiently.[1] Flight, therefore, is a question of power, speed, and small surfaces *versus* weight. While there is apparently no fixed relation between the area of the wing and the animal to be raised, there is (unless in the case of sailing birds, which have acquired momentum) an unvarying relation as to the weight to be elevated and the number of oscillations; so that the problem of flight would seem to resolve itself into one of weight, power, velocity, and small surfaces, as against comparative levity, debility, diminished speed, and extensive surfaces.[2] Elaborate measurements of wing area and minute calculations of speed can, consequently, only determine the minimum of wing for elevating the maximum of weight—flight being attainable within a wide range. This is proved by the fact that as much as four-sixths may in some instances be removed from the wing area without destroying flight. In such cases the speed with which the wings are driven is increased in the direct ratio of the mutilation. That the superficies of the wings destined to carry a certain weight may, and does vary, is proved by the fact that large portions of the wings of insects and birds, as I have pointed out,[3] may be removed without destroying or even impairing the function of flight. It is further proved by the ingenious researches of M. de Lucy, who has shown, by careful measurements, that the area of the wings decreases as the size and weight of the body increase.

§ 433. Flight of Gannet as Witnessed at the Bass Rock, Firth of Forth, Scotland.

The wings and body of the gannet, as I fully satisfied myself from actual observation, can be moved in all their parts. The wings and body are, moreover, thoroughly under control. The body can be twisted about in a remarkable manner; in an upward and downward direction and sideways. The individual primary, secondary, and tertiary feathers of the wing are likewise under control. In fact, the muscular movements can be seen extending along the pinion to the roots of the rowing feathers, the muscular influence spreading thence to the tips of the wings. This could readily be ascertained, as the birds wheeled round and round right overhead, and within a very few yards of where I was standing.

When the gannet throws itself from a cliff, it makes a large curve, the convexity of which is directed downwards. It acquires speed and momentum by a few gentle flappings of the wings, or it holds the wings comparatively motionless, and sails for a great distance without effort—the weight of the trunk doing the principal portion of the work. In the sailing movement the body is forced into an upward or downward curve, according to circumstances.

When the bird has acquired momentum, either by flapping its wings or by projecting itself from a cliff, it has the air perfectly under control. If it wishes to turn to the right it elevates the left wing and depresses the right one, the head and neck bending in the direction of the curve to be described. If it would turn to the left the

[1] The grebes among birds and the beetles among insects furnish examples where small wings, made to vibrate at high speeds, are capable of elevating great weights.

[2] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom," by the Author. (*Trans. Linn. Soc.*, vol. xxvi., p. 219.)

[3] Ibid., pp. 219, 220, 221, 222.

movements are reversed.[1] If it desires to ascend, the head, neck, body, and wings are elevated in an upward direction, so as to increase the angle made by them with the horizon, the angle referred to being decreased or reversed when the bird wishes to descend. If the bird aims at horizontal flight, the head, neck, body, and wings are arranged so as to be nearly parallel with the surface of the sea. The gannet wheels and skims about with all imaginable ease and grace—now oscillating on the long axis of the body as a centre, and now upon the long axes of the wings as a centre. In all these movements the head, neck, tail, and body perform an important part.

When the gannet launches itself from a rock it rises to nearly the same level as that from which it precipitated itself, without any apparent effort, thus showing that the friction experienced in flight must be almost *nil.*

The neck, body, and tail of the gannet are exceedingly flexible, and admit of being curved in any direction. The feet are extended straight out behind the bird, and appear on the under surface of the tail. The body forms an elongated and very graceful ellipse, admirably adapted for cleaving the air and eluding resistance.

When the gannet propels itself by the more or less vertical flappings of its wings, the angles which the under surfaces of the wings and body make with the horizon are very considerable—something like 25° or 30°. Of this I convinced myself in a variety of ways.[2] When the bird has acquired speed and momentum, and begins to sail, the angle made by the under surfaces of the body and wings is reduced according to circumstances, and in some instances altogether obliterated, the bird gliding along for long distances with its body and wings apparently parallel to the surface of the ocean.

The wings of the gannet, when fully extended, are curved alternately forwards and backwards. Thus, the arm and hand are inclined backwards, and the forearm forwards. When the wings are flexed in ordinary flight the movement occurs principally at the wrist-joint; the arm and forearm bending comparatively little, and affording a wide basis of support both during the down and up strokes. In forced flight in flexion, the wing bends perceptibly at the elbow as well as the wrist, the wing during the up stroke forming a short lever, and being thrown into a fine arch, the convexity of which is directed upwards. The tip of the wing works out and in during the down and up strokes; and a close examination satisfied me that the bird has the power of forcing the posterior margin of its wings *into wave curves* while the wings are rising and falling *quite independently of the air.*

The down stroke is delivered with perceptibly greater rapidity and energy than the up stroke. Of this there can be no doubt whatever. This allows the air, set in motion by the wing during its descent, time to react on the under surface of the pinion so as to contribute to its elevation. This result is facilitated by the wing striking very decidedly *downwards and forwards.*

When the gannet alights at its nest it delivers a few very energetic strokes at right angles to the direction of its flight, and thus slows itself.

When the gannet plunges into the sea from a height it causes its body to assume a more or less vertical position, and descends with such impetuosity as to displace the water in an upward direction, until it attains an altitude of from 10 to 15 feet. It flies beneath the water with remarkable rapidity, and emerges without difficulty; the momentum acquired during the descent assisting it through and out of the water. In fact the gannet, when it swoops down to pick up a fish, simply describes a continuous downward curve in the water. Those movements, so numerous, varied, and beautiful, are all the result of volition. It is impossible to resist this conclusion after deliberate and careful watching.[3]

§ 434. A Regulating Power Necessary in Flight.

That the wing is propelled for the most part by voluntary movements, may be ascertained in the following manner.

If the sentient nerve of a pigeon's wing be divided (the motor nerve being left intact) the bird flutters most energetically, but altogether fails to fly.[4] In this experiment neither the flexibility, elasticity, nor the power which the wing possesses of moving in all its parts, are tampered with. The guiding or controlling power alone is impaired.

That the wing is made to vibrate intelligently admits of direct proof. Thus, if we hold a captured bird in the hand, we feel that it directs and controls the action of its wings in such a manner that a tractile force is pro-

[1] The swallow and swift, which dart along at a very high speed, tilt their bodies in turning; but, in addition, flap their wings and fly round the curve they wish to describe.

[2] In the dragon-fly, the anterior pair of wings make a smaller angle with the horizon than the posterior pair. The first pair of wings are, consequently, more actively engaged as propellers—the second pair as elevators.

[3] While studying the mechanism and movements of the gannet's wings, I had the good fortune to be presented with two fine living gannets caught in the nets of the fishermen at St. Andrews. These enabled me to study exhaustively the various movements referred to in the living and dead birds.

[4] "Experiments practically Demonstrating the Laws by which Birds fly," by Dr. W. Smyth. Second Annual Report of the Aëronautical Society of Great Britain for 1867.

duced, now in one direction now in another, in its efforts to escape ; nay more, that the force after a brief fluttering is concentrated at that point where it is most loosely held, and which offers the greatest chance of escape.

The wings of birds, as any one may readily ascertain by watching the flight of rooks, are visibly under control both during the down and up strokes. They are, moreover, deliberate leisurely movements. By leisurely movements, I mean such as are the result of design, and not such as would result from the sudden recoil of a merely elastic apparatus. Those who have watched, as I have frequently done, the rapid vibrations of natural and artificial wings, will readily understand the difference here indicated. In the living wing we have a smooth, soft, fanning, continuous movement, quite devoid of dead points ; whereas in artificial elastic wings, especially if worked vertically and without elastic bands at their roots, we have a wavering, jerking, irregular motion, particularly at the beginning of the up stroke.

The blow-fly can fly with only one-third of its original wing area, the two-thirds which represented the major part of the *elastic* portions of the wing being removed. In this case the wing is wielded intelligently figure-of-8 fashion, the mutilation not interfering either with the freedom of motion enjoyed by the pinion at its root, or the power the insect possesses of directing and controlling the wing throughout its entire vibration.

There are therefore at least five separate items to be considered in flight, namely, intelligence and voluntary movements ; secondly, the power which the wing possesses of moving in its several parts ; thirdly, the flexibility and elasticity of the wing ; fourthly, the resistance and resiliency of the air upon which the wing operates ; fifthly, the weight of the body of the flying animal, which may be regarded as an independent moving power.

§ 435. The Wing at all Times thoroughly under Control.

The wing is movable in all parts, and can be wielded intelligently even to its extremity ; a circumstance which enables the insect, bird, and bat to rise upon the air and tread it as a master—to subjugate it, in fact. The wing, no doubt, abstracts an upward and onward recoil from the air, but in doing this it exercises a selective and controlling power ; it seizes one current, evades another, and creates a third ; it feels and paws the air as a quadruped would feel and paw a treacherous yielding surface. It is not difficult to comprehend why this should be so. If the flying creature be living, endowed with volition, and capable of directing its own course, it is surely more reasonable to suppose that it transmits to its travelling surfaces the peculiar movements necessary to progression, than that those movements should be the result of impact from fortuitous currents which it has no means of regulating. That the bird, for example, requires to control the wing, and that the wing requires to be in a condition to obey the behests of the will of the bird, is pretty evident from the fact that most of our domestic fowls can fly for considerable distances when they are young and when their wings are flexible ; whereas when they are old and the wings stiff, they either do not fly at all or only for short distances, and with great difficulty. This is particularly the case with tame swans. This remark also holds true of the steamer or race-horse duck (*Anas brachyptera*), the younger specimens of which only are volant. In older birds the wings become too rigid and the bodies too heavy for flight. Who that has watched a sea-mew struggling bravely with the storm, could doubt for an instant that the wings and feathers of the wings are under control ? The whole bird is an embodiment of animation and power. The intelligent, active eye, the easy, graceful oscillation of the head and neck, the folding or partial folding of one or both wings—nay more, the slight tremor or quiver of the individual feathers of parts of the wings, so rapid that only an experienced eye can detect it—all confirm the belief that the living wing has not only the power of directing, controlling, and utilising natural currents, but of creating and utilising artificial ones. But for this power, what would enable the bird and bat to rise and fly in a calm, or steer their course in a gale ? It is erroneous to suppose that anything is left to chance where living organisms are concerned, or that animals endowed with volition and travelling surfaces should be denied the privilege of controlling the movements of those surfaces quite independently of the medium on which they are destined to operate. I will never forget the gratification afforded me on one occasion at Carlow (Ireland) by the flight of a pair of magnificent swans. The birds flew towards and past me, my attention having been roused by a peculiarly loud whistling noise made by their wings. They flew about fifteen yards from the ground, and as their pinions were urged not much faster than those of the heron, I had abundant leisure for studying their movements.[1] The sight was very imposing, and as novel as it was grand. I had seen nothing before,

[1] I have frequently timed the beats of the wings of the common heron (*Ardea cinerea*) in a heronry at Warren Point. In March 1869, I was placed under unusually favourable circumstances for obtaining trustworthy results. I timed one bird high up over a lake in the vicinity of the heronry for fifty seconds, and found that in that period it made fifty down and fifty up strokes ; that is, one down and up stroke per second. I timed another one in the heronry itself. It was snowing at the time (March 1869), but the birds, notwithstanding the inclemency of the weather and the early time of the year, were actively engaged in hatching, and required to be driven from their nests on the top of the larch trees by knocking against the trunks thereof with large sticks. One unusually anxious mother refused to leave the immediate neighbourhood of the tree containing her tender charge, and circled round and round it right overhead. I timed this bird for ten seconds, and found that she made ten down and ten up strokes ; that is, one down and one up stroke per second precisely as before. I have therefore no hesitation in affirming that the heron, in ordinary flight, makes exactly sixty down and sixty up strokes per minute. The heron, however, like all other birds when pursued or agitated, has the power of greatly augmenting the number of beats made by its wings.

and certainly have seen nothing since, that could convey a more elevated conception of the prowess and guiding power which birds may exert. What particularly struck me was the perfect command they seemed to have over themselves and the medium they navigated. They had their wings and bodies visibly under control, and the air was attacked in a manner and with an energy which left little doubt in my mind that it played quite a subordinate part in the great problem before me. The necks of the birds were stretched out, and their bodies to a great extent rigid. They advanced with a steady, stately motion, and swept past with a vigour and force which greatly impressed, and to a certain extent overawed, me. Their flight was what one could imagine that of a flying machine constructed in accordance with natural laws would be.[1]

ANALYSIS OF THE DOWN AND UP STROKES OF THE WING OF THE BIRD IN FLAPPING OR ROWING FLIGHT

As considerable confusion exists in the minds of most investigators as to the precise changes made by the wing during the *down* and *up* strokes respectively, and, in especial, as to the manner in which the wing is elevated, so as to avoid the resistance of the air and yet afford support, I have felt it incumbent upon me carefully to analyse the movements as observed in progressive flight.

In all wings, whatever their position during the intervals of rest, and whether in one piece or in many, this feature is to be observed in flight. The wings are slewed downwards and forwards, that is, they are carried more

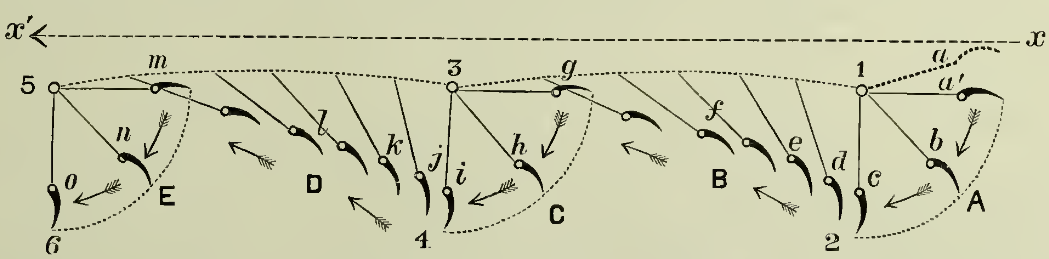


FIG. 534.—Analysis of the movements made by the wing of the bird during the down and up strokes, also the angles made by its under surface with the horizon as it rises and falls. The wing is seen in transverse section from letters *a* to *o* inclusive. *x*, *x'*, Line of the horizon ; 1, 3, 5, body of bird ; *a*, *a'*, *b*, *c*, down stroke (A) of wing ; *d*, *e*, *f*, up stroke (B) of wing ; *g*, *h*, *i*, a second down (C) stroke ; *j*, *k*, *l*, a second up stroke (D) ; *m*, *n*, *o*, a third down stroke (E), (the Author, 1870).

or less in the direction of the head during their descent, and reversed or carried in an opposite direction during their ascent. In stating that the wings are carried away from the head during the back or up stroke, I wish it to be understood that they do not therefore necessarily travel backwards in space when the bird is flying forwards. On the contrary, the wings, as a rule, move forward in curves, both during the down and up strokes. The fact is, that the wings at their roots are hinged and geared to the body so loosely that the body is free to oscillate in a forward or backward direction, or in an up, down, or oblique direction. As a consequence of this freedom of movement, and as a consequence likewise of the speed at which the bird is travelling, the wings during the back or up stroke are for the most part actually travelling forwards. This is accounted for by the fact that the body falls downwards and forwards in a curve during the up or return stroke of the wings, and because the horizontal speed attained by it is so much greater than that attained by the wings, that the latter are never allowed time to travel backward, the lesser movement being, as it were, swallowed up by the greater. For a similar reason, the passenger of a steamship may travel rapidly in the direction of the stern of the vessel, and yet be carried forward in space—the ship sailing much quicker than he can walk.

While the wing is descending, it is rotating upon its root as a centre (short axis). It is also (and this is a most important point) rotating upon its anterior margin (long axis), in such a manner as to cause the several parts of the wing to assume various angles of inclination with the horizon.

Fig. 534 supplies the necessary illustration.

In Fig. 534 the body of the bird is represented at 1, 3, and 5 ; transverse sections of the wing (during the down and up strokes), being seen at the letters *a* to *o* inclusive. The down strokes are indicated at A, C, and E, the up strokes at B and D. Fig. 534 brings into strong relief the various angles made by the wing with the horizon (x, x') during the down and up strokes. It also emphasises the important fact that the under concave surface of the wing acts as a kite during both strokes, and has, practically, no slip.

As the wing descends, which it does in a *downward and forward direction*, the posterior margin is screwed down-

[1] The above observation was made at Carlow on the Barrow in October 1867, and the account of it is taken from my notebook.

wards and forwards until it assumes a nearly vertical position (*c*, *i*, *o*); the rotation of the posterior margin round the anterior margin causing the different portions of the under surface of the wing to assume various angles of inclination with the horizon (letters *a* to *o* inclusive); the wing attacking the air like a boy's kite. The angles are greatest towards the root of the wing and least towards the tip. They accommodate themselves to the speed at which the different portions of the wing travel—a small angle with a high speed giving the same amount of buoying power as a larger angle with a diminished speed. The screwing of the under surface of the wing (particularly the posterior margin) in a downward and forward direction during the down stroke is necessary to ensure a sufficient upward and forward recoil; the wing being made to swing downwards and forwards pendulum fashion, for the purpose of elevating and propelling the body, which it does by acting upon the air as a long lever, and after the manner of a kite. During the down stroke the wing is active, the air passive; the wing being depressed by a purely vital act, and at varying degrees of speed; the speed being greatest at the beginning of the down stroke; when the wing frequently emits a loud clapping sound, as in the flight of the pigeon.

The down stroke is readily explained, and its results upon the body are obvious. The real difficulty begins with the up or return stroke. If the wing were simply to travel in an upward and backward direction, it is evident that it would experience much resistance from the superimposed air, and undo or negative the advantages secured by its descent. What really happens is this. The wing does not travel upwards and *backwards* (the body, be it remembered, is advancing), but upwards and *forwards*. This is brought about in the following manner. The wing is at nearly right angles to the horizon at the end of the down stroke (see Plate clxxv., Fig. 2, upper bird, p. 1269). It is, therefore, caught by the air because of the more or less horizontal travel of the body; the elastic ligaments and other structures rotating the posterior or thin margin of the pinion in an upward direction. The wing by this partly vital and partly mechanical arrangement is rotated off the wind in such a manner as to keep its dorsal or non-biting surface directed upwards, while its concave or biting surface is directed downwards. The wing, in short, has its planes so arranged, and its angles so adjusted to the speed at which it is travelling, that it darts up a gradient like a true kite. The wing consequently elevates and propels during its *ascent* as well as during its *descent*. It is, in fact, a kite during both the down and the up strokes. The ascent of the wing is greatly assisted by the *forward* travel of the body. It is further assisted by the downward and forward fall of the body. This view will be readily understood by supposing, what is really the case, that the wing at the end of the down stroke is more or less fixed by the air in space, and that the body, the instant the wing is fixed, falls downwards and forwards in a curve, which, of course, is equivalent to placing the wing above, and, so to speak, behind the bird—in other words, to elevating the wing preparatory to a second down stroke.

When a bird rises from the ground it runs for a short distance, or throws its body into the air by a sudden leap; the wings being simultaneously elevated. When the body is fairly off the ground, the wings are made to descend with great vigour, and by their action to continue the upward and forward impulse secured by the preliminary run or leap. The body then falls in a curve downwards and forwards, the wings, partly by the fall of the body, partly by the reaction of the air on their under surface, and partly by the contraction of the elevator muscles and elastic ligaments, being placed above, and to some extent behind the bird—in other words, elevated. The second down stroke is now given, and the wings are again elevated as explained, and so on *ad infinitum;* the body falling when the wings are being elevated, and *vice versâ*.

When the long-winged oceanic bird rises from the sea, it uses the tips of its wings as levers for forcing the body up, the points of the pinions suffering no injury from being brought violently in contact with the water. A bird cannot be said to be flying until the trunk is swinging forward in space and taking part in the movement. The hawk, when fixed in the air over its quarry, is simply supporting itself. To fly, in the proper acceptation of the term, implies to support and propel. This constitutes the difference between a bird and a balloon. The bird can elevate *and carry itself forward*, the balloon can simply elevate itself, and must rise and fall in a straight line in the absence of air currents. When the gannet throws itself from a cliff the inertia of the trunk at once comes into play, and relieves the bird from those herculean exertions required to raise it from the water when it is once fairly settled thereon. A swallow dropping from the eaves of a house, or a bat from a tower, afford illustrations of the same principle.[1]

[1] Many insects launch themselves into space prior to flight. Some, however, do not. Thus the blow-fly can rise from a level surface when its legs are removed. This is accounted for by the greater amplitude and more horizontal play of the insect's wing as compared with that of the bird and bat, and likewise by the remarkable reciprocating power which it possesses when the body of the insect is not moving forwards. When a beetle attempts to fly from the hand it extends its front legs and flexes the back ones, and tilts its head and thorax upwards so as exactly to resemble a horse in the act of rising from the ground. This preliminary over, whirr go its wings with immense velocity, and in an almost horizontal direction, the body being inclined more or less vertically. The insect rises very slowly, and often requires to make several attempts before it succeeds in launching itself into the air. I could never detect any pressure communicated to the hand when the insect was leaving it, from which I infer that it does not leap into the air. The bees, I am disposed to believe, also rise without anything in the form of a leap or spring. I have often watched them leaving the petals of flowers, and they always appeared to me to elevate themselves by the steady play of their wings, which was the more necessary, as the surface from which they rose was in many cases a yielding surface.

§ 436. The Body is made to Ascend when the Wings Descend, and *vice versâ*.

The manner in which the body falls downwards and forwards during the up stroke in progressive flight is illustrated at Figs. 534 (p. 1283), 535, and 536.

At Fig. 535 the body is represented at *a* and *c*, the wing at *b* and *d*; *x* supplying the fulcrum or pivot on which the body and wing oscillate. The letters *e*, *f* and *g*, *h* represent segments of circles described by the body and wing respectively.

If the wing (*b*) be depressed in the direction *h*, and made to assume the position *d*, it causes the body (*a*) to ascend to *c*. If, on the other hand, the wing (*d*) be elevated in the direction *g* until it assumes the position *b*, it causes the body (*c*) to fall to *a*. The force of gravitation largely accounts for the fall of the body during the up stroke. The ascent or descent of the wing is always very much greater than that of the body, from the fact of the pinion acting as a long lever. The remarks just made are true more especially of the body and wing when oscillating on either side of the fixed point *x*, this furnishing the fulcrum on which the body and the wing alternately act. The peculiarity, however, of the wing and the wing movements consists in the fact that the wing is a flexible lever and acts upon yielding fulcra (the air), the body participating in, and to a certain extent perpetuating, the movements originally produced by the pinion. The part which the body performs in progressive flight is illustrated at Fig. 536. At *a* the body is depressed, the wing being elevated and ready to make the down stroke at *b*. The wing descends in the direction *c*, *d*, but the moment it begins to descend the body moves *upwards and forwards* (see arrows) in a curve to *e*. As the wing is attached to the body it is made gradually to assume the position *f*. The body is now elevated and the wing depressed, the under surface of the latter being so adjusted that it strikes upwards and forwards as a kite would. The body now falls *downwards and forwards* in a curve to *i*, and in doing this it elevates or assists in elevating the wing to *j*. The pinion is a second time depressed in the direction *g*, *h*, which has the effect of forcing the body along a waved track and in *an upward direction* until it reaches the point *k*. The ascent of the body is produced by the descent of the wing as at *l*. The body and wing, as will be seen from this figure, are alternately above and beneath a given line *x*, *x′*.

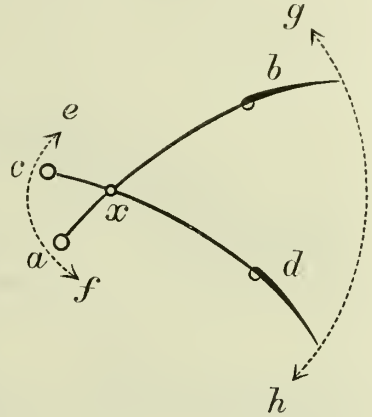


Fig. 535.

A careful study of Figs. 534, 535, and 536 shows the great importance of the twisted configuration and curves peculiar to natural wings. If the wing were not curved in every direction it could not be rolled on and off the

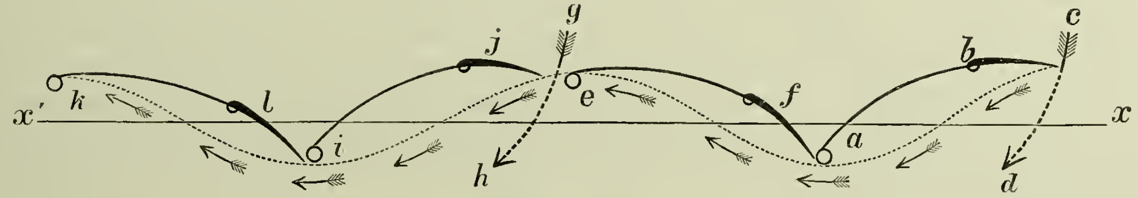


Fig. 536.

wind during the down and up strokes, as shown more particularly at Fig. 536. This, however, is a vital point in progressive flight. The wing (*b*) is rolled on to the wind in the direction *c*, *d*, its under concave or biting surface being crushed hard down with the effect of elevating the body to *e*. The body falls to *i*, and the wing (*f*) is rolled off the wind in the direction *e*, and elevated partly by the action of the elevator muscles and elastic ligaments, and partly by the reaction of the air, operating on its under or concave biting surface, until it assumes the position *j*. The wing is therefore to a certain extent resting during the up stroke. The concavo-convex form of the wing is admirably adapted for the purposes of flight. In fact, the power which the wing enjoys of always keeping its concave or under surface directed *downwards* and more or less *forwards* enables it to seize the air at every stage of both the up and down strokes so as to supply a persistent buoyancy. The action of the natural wing is accompanied by remarkably little slip—the body, air, elastic ligaments, and muscles all co-operating and reciprocating with remarkable precision and effect, the descent of the wing elevating the body, the descent of the body, aided by the reaction of the air and the contraction of the elastic ligaments and muscles, elevating the wing—this during the up stroke *arching above the body* after the manner of a parachute, and in turn preventing the body from falling. The sympathy which exists between the several parts of a flying animal and the air on which it depends for support and progress is consequently of the most intimate character.

The up stroke (B of Fig. 534), as will be seen from the foregoing account, is a compound movement due in some measure to recoil or resistance on the part of the air, to the action of the elevator muscles, elastic ligaments, and other vital structures, to the elasticity of the wing, and to the falling of the body in a downward and forward direction. The body, the elastic ligaments, the muscles, and the air, are active and passive by turns during the down and up strokes ; the depressor muscles and elastic properties of the wing being called into play during the down stroke, and the elevator muscles, the elastic ligaments, the weight of the body, and the reaction of the air during the up stroke.

§ 437. The Natural Wing when Elevated and Depressed must move Forwards.

It is a condition of natural wings, and of artificial wings constructed on the principle of living wings, that when forcibly elevated or depressed, even in a strictly vertical direction, they inevitably dart forward. This is well shown in Fig. 537, first published by me in 1870.[1]

If, for example, the wing be suddenly depressed in *a vertical direction*, as represented at *a*, *b*, it at once darts downwards and forwards in a curve to *c*, thus converting the vertical down stroke into *a down, oblique, forward stroke.* If, again, the wing be suddenly elevated in a strictly vertical direction, as at *c*, *d*, the wing as certainly darts upwards and forwards in a curve to *e*, thus converting the vertical up stroke into an *upward, oblique, forward stroke.* The same thing happens when the wing is depressed from *e* to *f*, and elevated from *g* to *h*. In both cases the wing describes a waved track, as shown at *e*, *g* ; *g*, *i*, which clearly proves that the wing strikes *downwards and forwards* during the down stroke, and *upwards and forwards* during the up stroke. The wing, in fact, is always advancing ; its under surface attacking the air like a boy's kite. If, on the other hand, the wing be forcibly depressed, as indicated by the heavy waved line *a*, *c*, and left to itself, it will as surely rise again and describe a waved track, as shown at *c*, *c*. This it does by rotating on its long axis, and in virtue of its flexibility and elasticity, aided by the recoil obtained from the air.

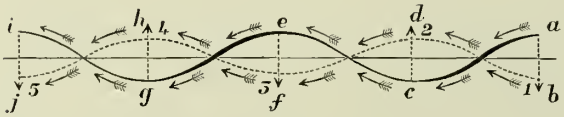


Fig. 537.

In other words, it is not necessary to elevate the wing forcibly in the direction *c*, *d* to obtain the upward and forward movement *c*, *e*. One single impulse, communicated at *a*, causes the wing to travel to *e*, and a second impulse, communicated at *e*, causes it to travel to *i*. It follows from this that a series of vigorous down impulses would, *if a certain interval were allowed to elapse between them*, beget a corresponding series of up impulses, in accordance with the law of action and reaction ; the wing and the air under these circumstances being alternately active and passive. I say if a certain interval were allowed to elapse between every two down strokes, but this is practically impossible, as the wing is driven with such velocity that there is positively no time to waste in waiting for the purely mechanical ascent of the wing. That the ascent of the pinion is not, and ought not to be, entirely due to the reaction of the air, is manifest from this, that in flying creatures (certainly in the bird and bat) there are distinct elevator muscles and elastic ligaments delegated to the performance of this function. The reaction of the air is therefore only one of the forces employed in elevating the wing ; the others, as I shall show presently, are vital and vito-mechanical in their nature. The falling downwards and forwards of the body when the wings are ascending also contributes to this result.

The accuracy of my statement as to the forward travel of the wing during the down and up strokes may be readily verified by a very simple experiment.

If I take a piece of bamboo cane, and, by the aid of a joiner's plane, convert it into a finely tapered, graduated elastic structure which bends in a graceful arch in an upward or downward direction under pressure applied to its tip and weaker portions ; if, further, I fix to the flat or shaved surface of the cane three portions of finely tempered, highly springy, ribbon steel, each of which is also made to taper to a point, I get at once the skeleton of a genuine wing. I have, for the sake of simplicity, fixed the three portions of ribbon steel to the bamboo cane at right angles, but in the natural wing (to be quite accurate) the ribbon steel portions of the structure would have to be greatly increased in number and to radiate towards the tip of the wing. If to the skeleton wing, produced as explained, I add a covering of buckram or net, the interstices of which are filled with a film of starch, such as is employed for stiffening purposes in tailoring and in dress and bonnet making, I produce a perfectly serviceable wing, which, when set in motion and guided by the hand, reproduces all the natural wing movements, especially the *forward* ones. Such a simple artificial wing is represented at Fig. 538.

In the figure at A, the wing (*a*, *b*, *c*, *d*) is being depressed (*g*, *g*, *g*) by the right hand as in the down stroke ; the ruled, diamond-shaped, dark portion (*h*, *h*, *h*, *h*) of the figure representing the nether air which resists the descent

[1] "The Physiology of Wings." (*Trans. Roy. Soc. Edin.*, vol. xxvi., p. 344.)

of the wing. When the wing is made to descend the tapering bamboo cane (*a*, *b*), which is semi-rigid under slight pressure, yields little. It is otherwise with the posterior margin (*c*, *d*), which yields in an upward direction to a considerable extent. The degree of upward yielding is indicated at *e*, *f*, by a prolongation of the middle portion of ribbon steel. What happens is this. The hand forces the wing in a downward direction (*g*, *g*, *g*) : the nether air (*h*, *h*, *h*, *h*) resists the descent and forces the posterior, thin, elastic margin (*c*, *d*) upwards in a curve, with the result that the whole wing travels downwards and *forwards* in a curve in the direction of the dart (*i*).

Precisely the same thing happens in the up stroke as represented at B of Fig. 538. At B, the tapered semi-rigid bamboo cane which forms the anterior margin of the wing is seen at *i*, *j* ; the thin, posterior, highly elastic margin at *k*, *l* ; the prolonged portion of ribbon steel at *m*, *n* ; and the superimposed air at *p*, *p*, *p*, *p*.

When the wing is elevated in the direction *o*, *o*, *o*, by the hand, the superimposed air offers resistance, more especially to the thin, elastic, posterior margin of the wing, and forces it into a curve as at *n*, with the result that the wing flies upwards and *forwards* in a curve as indicated by the dart marked *q*.

This unlooked-for result is further illustrated at C of Fig. 538, where a finely tapered steel rod (*r*, *s*), a graduated portion of ribbon steel (*t*) soldered to it at right angles, and a fixed loop (*x*), within which the ribbon steel is placed, are employed. When the rod is depressed by the hand at *r*, the posterior portion of the ribbon steel caught in the fixed loop (*x*) is bent in an upward curve, with the result that the steel rod itself inevitably travels downwards and *forwards* in a curve. Exactly the same thing happens when the steel rod is elevated. In this case, the ribbon steel is bent in an upward curve (*vide* interrupted curved line) ; with the result that the steel rod is made to travel in an upward and *forward* curve. The wing and the steel rod take the line of least resistance during both the down and up strokes, hence the downward and upward forward curves in either case. The downward and forward curves are united in progressive flight, and form the waved trajectory in the air characteristic of free flight.

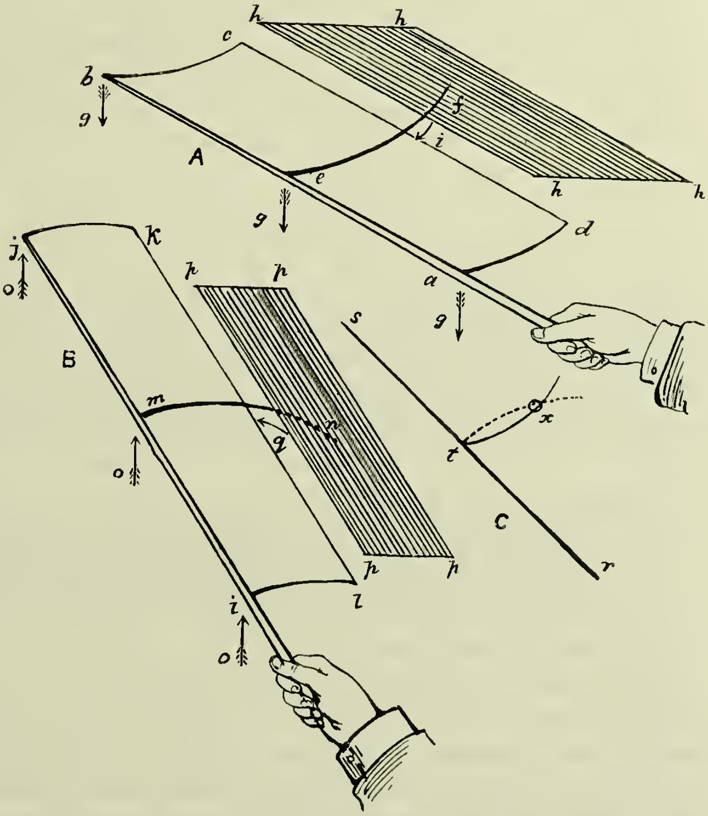


Fig. 538.

As I showed in 1870, the body of the insect, bird, and bat falls forwards in a curve when the wing ascends, and is elevated in a curve when the wing descends. It follows that the trunk of the animal is urged along a waved line, as represented at 1, 2, 3, 4, 5, of Fig. 537 ; the waved line *a*, *c*, *e*, *g*, *i* of the same figure giving the track made by the wing. I have distinctly seen the alternate rise and fall of the body and wing when watching the flight of the gull from the stern of a steamboat.

The direction of the stroke in the insect, as has been already explained, is much more horizontal than in the bird or bat. In either case, however, the down stroke must be delivered in a more or less forward direction. This is necessary for support and propulsion. A horizontal to-and-fro stroke will elevate, and an up-and-down vertical one propel, but an oblique forward stroke is requisite for progressive flight.

§ 438. The Body and Wings move in Opposite Curves.

I have stated that the wing advances in a waved line, as shown at *a*, *c*, *e*, *g*, *i* of Fig. 537 ; and similar remarks are to be made of the body as indicated at 1, 2, 3, 4, 5 of that figure. Thus, when the wing descends in a curved line *a*, *c*, it elevates the body in a similar but opposite and minor curved line, as at 1, 2 ; when, on the other hand, the wing ascends in the curved line *c*, *e*, the body descends in a similar but opposite and smaller curved line (2, 3), and so on *ad infinitum*. The undulations made by the body are so trifling when compared with those made by the wing, that they are apt to be overlooked. They are, however, deserving of attention, as they exercise an important influence on the undulations made by the wing ; the body and wing swinging forward alternately ; the one rising

when the other is falling, and *vice versâ*. Flight may be regarded as the resultant of three forces—the *muscular and elastic force*, residing in the wing, which causes the pinion to act as a true kite, both during the down and up strokes ; the *weight of the body*, which becomes a force the instant the trunk is lifted from the ground in a forward direction from its tendency to fall downwards and forwards ; and *the recoil obtained from the air* by the rapid action of the wing. These three forces may be said to be active and passive by turns.

The alternate rise and fall of the wing and body in progressive flight, first described and figured by me in 1870,[1] under the heading, "When the Wing ascends the Body descends, and *vice versâ*," were fully confirmed by Professor E. J. Marey by the aid of instantaneous photography in 1887, seventeen years after I wrote. I append his figure, as it affords another example of the many important points in which I have anticipated this author.

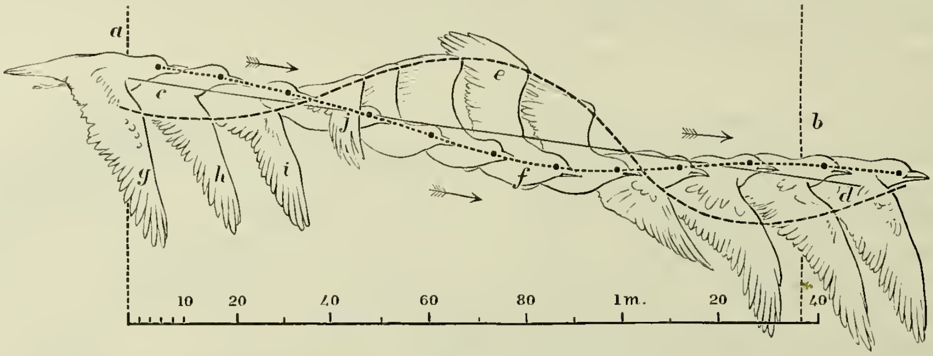


FIG. 539.—Photograph of the flight of the gull ; fifty pictures taken per second. From *a* to *b* is represented one revolution of the wing. A straight line (*c*, *d*) indicates the axis of flight. A dotted line (*f*) enables us to follow the vertical oscillations of the eye of the bird. An interrupted line (*e*) shows the trajectory made by the wrist of the wing in a revolution of the wing. *g*, The wing fully extended at the end of the down stroke ; *h*, *i*, the wing being flexed preparatory to making the up stroke. Below is a scale to measure the size of the bird and the spaces traversed. (Epitome of a Memoir by Professor E. J. Marey "On the Mechanism of the Flight of Birds studied by the Aid of Photochromography," extracted from the *Comptes Rendus* of the sittings of the Academy of Sciences, vol. civ., meeting of the 24th of January, 1887.)

§ 439. Birds fly by causing their large, powerful Wings to act upon the Air as Kites ; the Air furnishing a suitable Fulcrum for supporting and carrying them upwards and forwards. The Wings are propelled by voluntary, well-directed Muscular Movements, aided by certain Elastic Structures which contribute to the continued Vibrations of the Wings. In Flight, Weight and Momentum play an important part.

The various movements involved in ascending, descending, wheeling, gliding, and progressing horizontally, are all the result of muscular power and weight, properly directed and acting upon appropriate wing surfaces—that apparent buoyancy in birds, which we so highly esteem, arising not from superior lightness, but from their possessing that degree of solidity which enables them to subjugate the air—weight and independent motion, that is motion associated with animal life, or what is equivalent thereto, being the two things indispensable in successful aërial progression. The weight in insects and birds is in great measure owing to their greatly developed muscular system, this being in that delicate state of tonicity which enables them to act through its instrumentality with marvellous dexterity and power, and to expend or reserve their energies, which they can do with the utmost exactitude, in their apparently interminable flights.

§ 440. Lifting Capacity of Birds.

The muscular power in birds is usually greatly in excess, particularly in birds of prey—as, for example, the condors, eagles, hawks, and owls. The eagles are remarkable in this respect—these having been known to carry off young deer, lambs, rabbits, hares, and, it is averred, even young children. Many of the fishing birds, as the pelicans and herons, can likewise carry considerable loads of fish ;[2] and even the smaller birds, as the records of spring show, are capable of transporting comparatively large twigs for building purposes. I myself have seen a tame owl, which weighed a little over 10 ounces, lift and fly off with $2\frac{1}{2}$ ounces of steak, or a quarter of its own weight, without effort, after having fasted twenty-four hours ; and a friend informs me that a short time ago a splendid osprey was shot at Littlehampton, on the coast of Sussex, with a fish 5 lbs. weight in its mouth.

[1] "On the Physiology of Wings." (*Trans. Roy. Soc. Edin.*, vol. xxvi., pp. 343, 344, and 345, Fig. 14.)

[2] The heron is in the habit, when pursued by the falcon, of disgorging the contents of his crop in order to reduce his weight. The herons are reedy, indiscriminate feeders. One one occasion I extracted a full-grown mole from the crop of one of them.

§ 441. Mode of Ascending, Descending, Turning, &c.

All birds which do not, like the swallow and humming-birds, drop from a height, raise themselves at first by a vigorous forward leap, in which they incline their bodies in an upward direction, the height thus attained enabling them to extend and depress their wings without injury to the feathers. By a few sweeping strokes delivered downwards and forwards, in which the wings are made nearly to meet above and below the body, they lever themselves upwards and forwards, and, in a surprisingly short time, acquire that degree of momentum which greatly assists them in their future career. In rising from the ground, as may readily be seen in the crow, pigeon, and kingfisher, the tail is expanded and the neck stretched out, so that the body is converted into an inclined plane, and acts mechanically as a kite. The centre of gravity and the position of the body are changed at the will of the bird by movements in the neck, feet, and tail, and by increasing or decreasing the angles which the under surface of the wings makes with the horizon. When a bird wishes to fly in a horizontal direction, it causes the under surface of its wings to make a slight *forward* angle with the horizon. When it wishes to ascend, the angle is increased. When it wishes to descend, it causes the under surface of the wings to make a slight *backward* angle with the horizon. When a bird flies up, its wings strike downwards and *forwards*. When a sufficient altitude has been attained, the length of the downward stroke is generally curtailed, the mere extension and flexion of the wing, assisted by the weight of the body, in such instances sufficing. This is especially the case if the bird is advancing against a light breeze, the effort required under such circumstances being nominal in amount. That little power is expended is proved by the endless gyrations of rooks and other birds ; these being continued for hours together. In birds which glide or skim, it has appeared to me that the wing is recovered much more quickly, and the down stroke delivered more slowly, than in ordinary flight—in fact, that the rapidity with which the wing acts in an upward and downward direction is, in some instances, reversed ; and this is what we should naturally expect when we recollect that, in gliding, the wings require to be, for the most part, in the expanded condition. If this observation be correct, it follows that birds have the power of modifying the duration of the up and down strokes at pleasure. Although the wing of the bird usually strikes the air at an angle which varies from 15° to 30°, the angle may be increased to such an extent as to subvert the position of the bird. The tumbler pigeon, for example, can, by slewing its wings forwards and suddenly throwing back its head, turn a backward somersault. When birds are fairly on the wing they have the air, unless when that is greatly agitated by a storm, completely under control. This arises from their greater specific gravity, and because they are possessed of independent motion. If they want to turn, they have simply to tilt their bodies and wings laterally, as a railway carriage is tilted in taking a curve, or to increase the degree of pressure exerted by the one wing as compared with the other ; or to keep the one wing extended while the other is partially flexed. The neck, feet, and tail may or may not contribute to this result. If the bird wishes to rise, it tilts its entire body (the neck and tail participating) in an upward direction (Plate clxxv., Fig. 1, A, p. 1269) ; or it rises principally by the action of the wings and by muscular efforts, as happens in the lark. The bird can, by muscular wing action, even maintain a fixed position in the air, as may be observed in the hawk when hovering above its prey. If the bird desires to descend, it may reverse the direction of the inclined plane formed by the body and wings, and plunge head foremost with partially folded pinions (Plate clxxv., Fig. 1, B) ; or it may raise its wings and drop parachute-fashion ; or it may even fly in a downward direction—a few sudden strokes, a more or less abrupt curve, and a certain degree of horizontal movement being in either case necessary to break the fall previous to alighting (Plate clxxv., Fig. 1, C). Birds which fish on the wing, as the osprey and gannet, precipitate themselves from incredible heights, and drop into the water with the velocity of a meteorite—the momentum which they acquire during their descent materially aiding them in their subaqueous flight. They emerge from the water and are again upon the wing before the eddies occasioned by their precipitous descent have well subsided, in some cases rising apparently without effort, and in others running along and beating the surface of the water for a brief period with their pinions and feet.

There are many points in the history and economy of birds which crave our sympathy while they elicit our admiration. Their indubitable courage and miraculous powers of flight invest them with a superior dignity, and secure for their order almost a duality of existence. The swallow, tiny and inconsiderable as it may appear, can traverse 1000 miles at a single journey ; and the albatross, despising compass and landmark, trusts himself boldly for weeks together to the mercy or fury of the mighty ocean. The huge condor of the Andes lifts himself by his sovereign will to a height where no sound is heard, save the airy tread of his vast pinions, and, from an unseen point, surveys in solitary grandeur the wide range of plain and pasture-land,[1] while the bald eagle, nothing daunted by the din and indescribable confusion of the queen of waterfalls, the stupendous Niagara, sits composedly on his giddy perch, until inclination or desire prompts him to plunge into or soar above the drenching mists which, shapeless and ubiquitous, perpetually rise from the hissing waters of the nether caldron.

[1] The condor, on some occasions, attains an altitude of six miles.

THE WINGS OF BATS

The bat enjoys a unique position in the history of locomotion. It is the only mammal which flies, and this it does without having air in its bones, and without being provided with air sacs and feathers, by the aid of a very ample, continuous, neuro-vascular, elastic membrane, supported by its arms, forearms, and hands, and also by the sides of its body, legs, and tail.

The wing of the bat presents some remarkable features, well seen in some of the larger species.

1. The dimensions of the wing are enormous, as compared with the body and legs.

2. It is relatively more developed than the wing of any bird. Not only is its length great, but it extends backwards along the side of the body and tail to its tip—the tail being, in some of the smaller bats, quite the length of the body itself.

3. It is markedly convex above and deeply concave beneath, especially towards the leg and tail, where it forms a concavo-convex parachute.

4. It is exceedingly sensitive, and its blood-vessels pulsate rhythmically: so sensitive is it that a bat can fly in a dark room with threads stretched across it without touching any of them.

5. Its membranous portion is stretched upon a springy, osseous framework, namely, the bones of the arm, forearm, and hand, the leg, and the tail.

6. It is mobile and elastic in all its parts, and can, during flight, be moved with great facility, so as to cause its under surface to make a great variety of angles with the horizon—the angles being least at the tip of the wing and greatest at the root.

7. It resembles the wing of the insect in being composed of a continuous, semi-transparent membrane, supported in every direction by semi-rigid, elastic structures.

8. It resembles the wing of the bird in having bone as its substratum, and in being jointed, so that it can be flexed during the up stroke and extended during the down stroke.

9. It differs from the wing of the bird in having no feathers, and in having the fingers of its hand free, that is, not run together and ossified.

The wing of the bat is a true fore limb, composed of a humerus or arm-bone united to the body by a ball-and-socket joint (shoulder-joint); a radius and ulna united to the humerus by a spiral hinge-joint (elbow-joint). It is also provided with carpal and metacarpal bones and five phalangeal or finger-bones which represent the hand. Of the five phalangeal or finger-bones, the thumb is truncated and terminates in a claw or hook; the index finger is also shortened; the third, fourth, and fifth fingers being very greatly elongated and perfect.

The wing of the bat differs from that of the bird, and the foreleg of the horse, especially as regards the *manus* or hand. It has, as stated, carpal and metacarpal bones, and five phalanges or finger-bones—two of these being considerably modified; the remaining three phalanges are of enormous dimensions as compared with the bones of the arm and forearm; the function of the three greatly elongated phalanges or finger-bones being to support the voluminous flying membrane, in conjunction with the side of the body, leg and tail. There is a less violent departure from the typical hand in the bat than in the hands of the bird and horse, but there is a sufficient amount of modification to make it quite clear that the wing of the bat is the outcome of design and the product of a far-reaching intelligence. It is no chance product, any more than is the wing of the bird or the foot of the horse. It is as well adapted for the purpose for which it was created as either the one or the other. It affords an example of the modification of the first and second metacarpal and phalangeal bones and quite a phenomenal development of the third, fourth, and fifth phalangeal or finger-bones. This partial suppression of growth in one direction, and the great increase of growth in another direction, is not the result of evolution, but simply decreased and increased growth for a purpose. It is retrogression in one sense; in another it is advance, and must be regarded as a perfection, seeing it secures the highest good for the animal, namely, a means of existence. Without its ample, beautifully constructed wings the bat would inevitably perish. Its wings are means to ends; they enable it to navigate the air and secure food of a kind adapted to its requirements.

The very large wings of the bat, coupled with its small body and dwarfed legs, forcibly remind us of the inexorable demands of the air as regards locomotion therein.

The wings of the bat rigidly conform to the type, if not the precise structure, of the wings of the insect and bird. Thus, they are triangular in shape, mobile, elastic, and carefully graduated—that is, they are thicker and stronger at the roots than at the tips. Their anterior margins are also thicker and stronger than their posterior margins. They are true organs of flight anatomically and physiologically.

While the bat is the only existing mammal which can fly, it is well to bear in mind that the galeopithecus or

flying lemur can all but fly. It is provided with what is virtually a flying membrane extending between its neck, sides, arms, legs, and elongated tail, which enables it to take long, gliding leaps from higher to lower levels, from trees and other lofty structures. Its flying membrane is, strictly speaking, a parachute, and endowed with no great amount of independent movement. Its hands are not modified in any way to support a flying membrane, and it cannot cause its anterior extremities to flap in an upward and downward direction as in the bat.

Another example of a parachute, gliding membrane is to be noted in the flying dragon. The membrane in this case is supported by the ribs—the arms, hands, legs and feet, which are typical structures, being left quite free.

The following is the account of the bat's wing given by me in 1867 : [1]—

§ 442. Where the Bat's Wing agrees with and differs from that of the Insect and Bird.

The wing of the bat bears a considerable resemblance to that of the insect, inasmuch as it consists of a delicate, semi-transparent, continuous membrane, supported in divers directions, particularly towards its anterior margin, by a system of stays or stretchers, which confer upon it the degree of rigidity requisite for flight. The supports in this instance consist of the bones of the arm, forearm, and hand, and as these fold upon themselves during the period of repose, they bear a certain analogy to the nervures in the wing of the beetle. Indeed, if the wing of the bat and that of some of the larger beetles be compared, they will be found to possess many features in common. They especially resemble each other in their general contour and the manner in which their horny and osseous supports taper from within outwards, and from before backwards. The wing of the bat varies in shape, as do the wings of insects and birds, in some cases being short and broad, in others elongated and narrow. It also differs as regards relative proportion, on some occasions being ample with regard to the body, in others comparatively scanty. It is, as a rule, deeply concave on its under or ventral surface, and in this respect resembles the wing of the Rasores or heavy-bodied birds. It differs from the wing of the bird in being supported, in addition to the bones of the arm, forearm, and hand, by the bones of the feet and tail, and likewise by the back and side of the body, and in presenting an uninterrupted or continuous membrane both in flexion and in extension. If the tail be long, the area of the wing is increased, this with the legs distending and supporting the membrane in a backward direction. This arrangement facilitates the evolutions of the bat on the wing, the elevation or depression of the feet and tail, and the spreading thereof, assisting it in ascending, descending, and turning.

§ 443. The Bones of the Wing of the Bat—the Spiral Configuration of their Articular Surfaces.

The bones of the arm, forearm, and hand are especially deserving of attention. The humerus is short and powerful, and twisted upon itself to the extent of a quarter of a turn. As a consequence, the axis of the shoulder-joint is nearly at right angles to that of the elbow-joint. Similar remarks may be made regarding the radius (the principal bone of the forearm), and the second and third metacarpal bones, with their phalanges, all of which are greatly elongated, and give strength and rigidity to the anterior or thick margin of the wing. The articular surfaces of the bones alluded to, as well as of the other bones of the hand, are spirally disposed with reference to each other, the long axes of the joints intersecting at nearly right angles. The object of this arrangement is particularly evident when the wing of the living bat, or of one recently dead, is extended and flexed as in flight.[2]

§ 444. Extension and Flexion in the Wing of the Bat.

In the flexed condition the humerus and the second and third metacarpal bones, with their phalanges, are parallel to each other, the radius and ulna being raised a little above the others ; and the fourth and fifth metacarpal bones, with their phalanges, a little below—the whole being parallel, or nearly parallel, with the long axis of the body. In the flexed state the surface of the wing is diminished to its utmost, so that it presents its narrow edge to the air. When extension takes place the elbow-joint is depressed and carried forwards, the wrist elevated and carried backwards, the metacarpal-phalangeal joints lowered and inclined forwards, and the distal-phalangeal joints slightly raised and carried backwards.[3] The movement of the bat's wing in extension is consequently a spiral one, the spiral running alternately from below upwards and forwards, and from above downwards and backwards. As the bones of the arm, forearm, and hand rotate in the direction of their length during the extensile act, it follows that the posterior or thin margin of the wing is rotated in a downward direction (the anterior or thick

[1] *Transactions of the Linnean Society*, vol. xxvi., pp. 238, 239, and 240.

[2] I had the good fortune, when dealing with this part of my subject, to obtain the body of one of the larger bats (a species of *Pteropus*) immediately after death. By its aid I was enabled to determine many points which had escaped me in previous examinations.

[3] The raising of the distal phalanges enables the bat to arrange the distal portions of the wing upon the back during extreme flexion when the animal is reposing.

PLATE CLXXVII

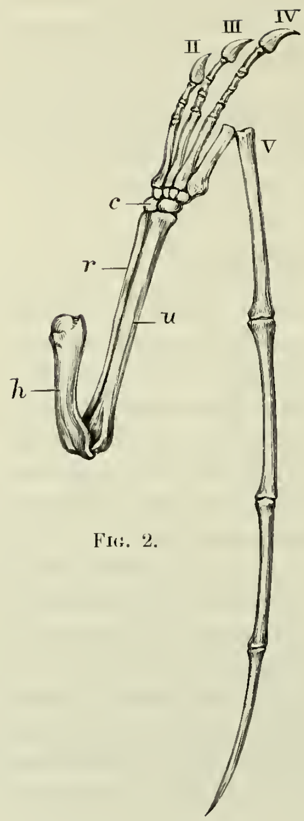


Fig. 2.

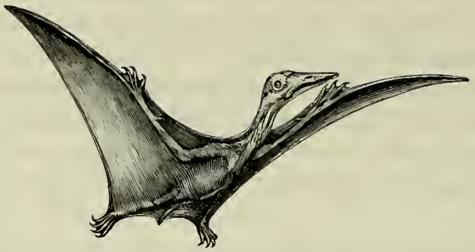


Fig. 3.

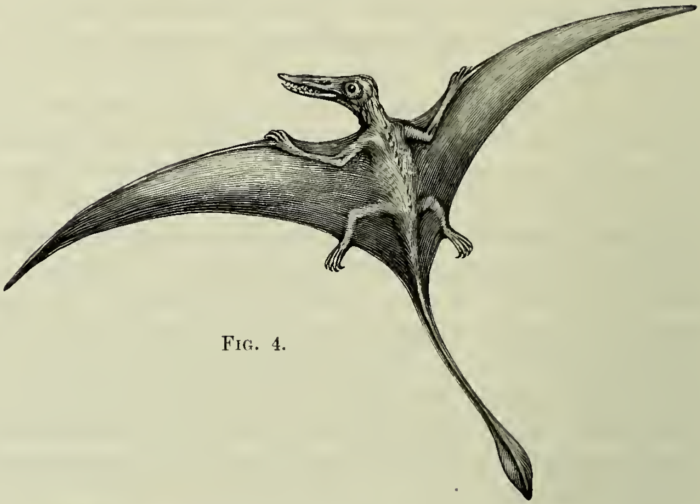


Fig. 4.

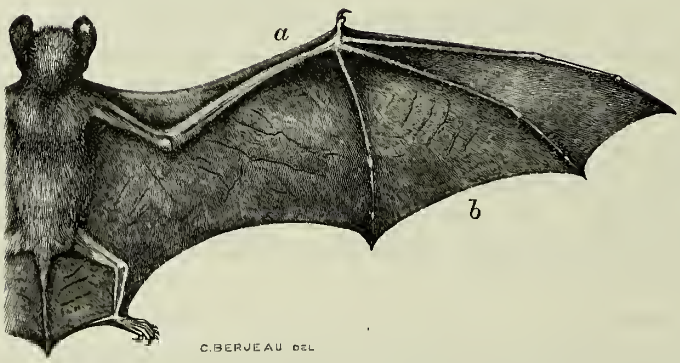


Fig. 1.

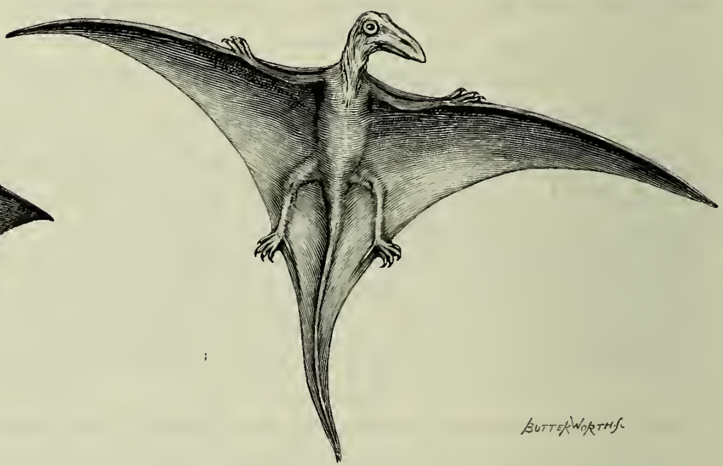


Fig. 5.

one being rotated in an opposite direction) until the wing makes an angle of 30° or thereby with the horizon. When the wing is fully extended it presents its concave or surface of greatest resistance, and is then in a position to give the effective or down stroke, which is delivered *downwards and forwards*, as in the insect. These movements are reversed during flexion. The action of the bat's wing at the shoulder is particularly free, partly because the shoulder-joint is universal in its nature, and partly because the scapula participates in the movements of this region. The freedom of action referred to enables the bat not only to rotate and twist its wing as a whole, and so diminish or increase the angle which it makes with the horizon, but to rotate or screw it in an upward and downward direction, and likewise in a forward and backward one. The rotatory or twisting movement of the wing is an essential feature in flight, as it enables the bat (and this holds true also of the insect and bird) to balance itself with the utmost exactitude, and to change its position and centre of gravity with marvellous dexterity. The movements of the shoulder-joint are restrained within certain limits by a system of check ligaments, and by the coracoid and

acromian processes of the scapula, and the wing is recovered or flexed by the action of an elastic ligament extending between the shoulder and the elbow along the anterior margin of the wing, and by elastic and fibrous structures situated between the fingers and in the substance of the wing generally. The bat flies with great ease and for lengthened periods. Its flight is remarkable for its softness, in which respect it surpasses the owl and the other nocturnal birds. The action of the wing of the bat, and the movements of its component bones, are essentially the same as in the bird. I had a striking demonstration of the absolutely noiseless flight of the bat in the great rock temple of Abû Simbel, on the Nile, in 1905. This celebrated edifice is dug out of the solid rock, and is famous, among other things, for its countless swarms of these quaint and interesting creatures. They are literally in thousands. If a piece of magnesian wire was suddenly ignited and burned, the roofs of the side chambers of the temple became a living, tangled, moving mass. It was a wonderful sight. The bats flew in tiers, some of them not more than four feet from the head. Everything, however, was as silent as the grave, and if one shut his eyes, it was impossible to detect their presence.

Illustrations of the wing of the bat and of the pterodactyl are given at Plate clxxvii.

PLATE CLXXVII

Plate clxxvii.—This plate illustrates the flight of the bat and pterodactyl, two of the most remarkable flying forms known to science. Both fly by the aid of a continuous elastic flying membrane, which is supported by the bones of the wing, namely, the humerus or arm-bone, the bones of the forearm, and certain of the bones of the hand, which are considerably modified. The wing is also supported by the side of the body, the leg, and tail.

Fig. 1.—The wing of the bat (*Phyllorhina gracilis*) shows the extensive connections of the flying membrane. It is supported by the bones of the arm, forearm, and hand, the side of the body, the dwarfed leg, and the tail. *a*, Tapering, anterior, semi-rigid margin of wing; *b*, thin, elastic, membranous, posterior margin of wing. Drawn from nature by C. Berjeau from the Author's collection.

Fig. 2.—Bones of the wing of the extinct flying reptile (*Scaphognathus crassirostris*). *h*, Humerus or arm-bone; *r*, *u*, radius and ulna; *c*, carpal bones; II, III, IV, hand and finger-bones terminating in claws; V, enormously elongated fifth metacarpal and phalangeal bones (after Nicholson and Lydekker).

Fig. 3.—The extinct flying reptile (*Pterodactylus spectabilis*)—ventral aspect. Restored by the Author and C. Berjeau and drawn by the latter.

Fig. 4.—The extinct flying reptile (*Rhamphorhynchus muensteri*)—dorsal aspect. Mark the long, pointed wing and large flying membrane extending backwards and terminating in a long tail. Restored by the Author and C. Berjeau.

Fig. 5.—The extinct flying reptile (*Dimorphodon macronyx*)—seen from before. Note the finely pointed wings and extensive flying membrane extending backwards on either side of the long tail; the whole forming a beautiful triangular kite, admirably adapted for sailing flight. Restored by the Author and C. Berjeau.

THE WINGS OF PTERODACTYLS (*Extinct flying reptiles*)

In ancient geologic time there were, so far as is known, no flying mammals. There were, however, a large number of flying reptiles (pterodactyls), some of which had an expanse of wing of more than 18 feet.

The pterodactyls included several species, ranging from the size of a pigeon upwards. They occur in the Mesozoic period. Their existence in that far-off time shows clearly enough that flight was one of the three great branches of locomotion instituted by the Creator for the progress from point to point of certain of His creatures on the earth's surface. In other words, flight was in no sense an after-thought, but a deliberate arrangement based on a preconceived plan, which had for its object the utilisation of the earth, water, and air as media for the transmission of animals in their search for food as a means of subsistence.

§ 445. The Wings of Pterodactyls are Original Structures in the Sense that they formed part of the Animals when created.

There was no process of evolution at work whereby wing structures and other organs of locomotion were manufactured from each other, or by environment, or at the desire and wish of particular animals. On the contrary, the organs of locomotion were supplied at the outset as integral parts of the animals which possessed them, and without which their existence would have been imperilled. No doubt, there are fixed animals and plants,

as well as animals and plants which move freely from place to place. The great scheme of nature is carried on in two ways, and both exhibit the highest conceivable wisdom and foresight. In the case of the fixed animals and plants, the food is brought to them; in the other instance, the food is placed at various points on the earth's surface, and the freely moving animals are provided with suitable organs of locomotion, which enable them to search for and secure it.

The existence of fins, wings, and feet, in primeval times, shows conclusively that they form, and have always formed, part of the apparatus of life.

§ 446. The Wings of Pterodactyls conform to the Requirements of Flight as witnessed in Insects, Birds, and Bats.

That wings and the other organs of locomotion are part of an original and carefully reasoned scheme of creation may be taken as certain, and especially when it is remembered that the travelling organs are formed on common types, and that all animals confining their operations to the land are provided with limbs and feet or their representatives; that all sea-going animals are provided with fins and swimming tails, or their homologues; and that all the animals destined to fly are furnished with wings. This view involves design and law and order in the organs of locomotion in animals, and is confirmed by the fact that all animals, to whatever order they belong, conform as regards their travelling surfaces to the requirements of the land, water, and air respectively.

Thus, in the matter of wings, certain insects, birds, and bats are provided with them in modern times, as certain extinct reptiles were provided with them in the past

The pterodactyls or flying reptiles are deserving of great consideration in this connection; and I give three original drawings and restorations, by C. Berjeau and myself, of these most interesting animals in Plate clxxvii., Figs. 3, 4, and 5.

§ 447. The Wings of Pterodactyls afford Examples of Extreme Modification for a Special Purpose.

The wing of the pterodactyl is structurally a very remarkable organ. As shown at Plate clxxvii., Fig. 2, it consists of an osseous or bony, semi-rigid part, and of a membranous, highly elastic part. The bony part is composed of a short, strong humerus or arm-bone with a rounded extremity forming part of a universal joint (shoulder-joint) at one end, and at the other a spiral hinge-joint. The humerus bone is also twisted in the direction of its length. The osseous part of the wing is further composed of a forearm consisting of a radius and ulna, a set of carpal or wrist-bones, five metacarpal bones, and five phalangeal or finger-bones.

The hand and finger-bones are very greatly modified for the purposes of flight. Thus, the second, third, and fourth metacarpals and phalangeal bones are comparatively short, and terminate in claws, whereas the fifth is enormously increased in size, both as regards its length and breadth, and curves in a direction from before backwards. It is the fifth metacarpal and fifth phalangeal or finger-bones which form the chief support for the continuous elastic membrane of the wing.

The flying membrane of the wing is composed of a comparatively thin, continuous membrane, which extends from the tip of the wing along the fifth phalangeal bones, fifth metacarpal bone, the radius and ulna, the humerus, the side of the body, the leg, and the side of the tail, which varies in length. Its connections are extensive, and its size very great as compared with the size of the animals, and there can be no doubt that the pterodactyls were splendid fliers. The size and shape of the wings equally confirm this view. The wings are long and pointed at their tips and unusually broad at their roots—this form of wing combining great elevating, propelling, and sustaining power. The tip and outer portions of the wing elevate and propel, the inner portions acting as parachutes for sustaining.

§ 448. Points wherein the Wings of Pterodactyls and Bats agree, and other Points wherein they differ.

There is a general resemblance between the wing of the pterodactyl and that of the bat (compare Figs. 3, 4, and 5 with Fig. 1 of Plate clxxvii.).

There is, however, one important difference. In the pterodactyl, the flying membrane is supported by the arm, forearm, fifth metacarpal bone and fifth digit, and by the side of the body, leg, and more or less elongated tail, whereas in the bat it is supported by the arm, forearm, and four digits, as well as by the other parts mentioned.

In the pterodactyl we have another example of a special modification for a purpose, indicating design, forethought, and the providing of "means to ends."

The bones of the hand of the pterodactyl (the fifth digit or finger excepted) take no part in flight. These are well developed, and, as stated, terminate in claws. They are, however, only a quarter of the size of the enormously developed fifth digit. The great length of this digit will be readily inferred when I state that it is nearly twice the length of the arm and forearm taken together.

§ 449. The Wings of Pterodactyls are produced not by dwarfing or obliterating original Typical Parts, but by the excessive Growth and Increase in Size of the Parts more especially connected with Flight.

While the second, third, and fourth digits of the wing of the pterodactyl afford no proof of dwarfing or retrogression, the fifth digit affords unmistakable evidence of extraordinary development or growth for a special purpose. It would be erroneous to suppose that this exuberant growth in a particular direction was a mere chance growth, or that it was due to environment or desire on the part of the reptile. Like other and similar growths and structures which are called upon to discharge particular functions, it is fundamental, and formed part of the original animal.

If it were destroyed, the life of the pterodactyl would be threatened, as its power of securing food would be rendered more than precarious, its limbs, hands, and feet being so trammelled and fixed as to be useless for the purpose of land travel.

§ 450. The Wings of Pterodactyls are triangular in Shape, elastic, carefully graduated Organs formed on a Common Type.

The pterodactyls, like insects, birds, and bats, are to be regarded as special creations. They conform to all the requirements of aërial navigation, that is, their wings are very large as compared with their bodies ; they are triangular in shape, and concavo-convex ; they taper from their roots towards their tips where they are thinnest ; they also taper from the anterior margins formed by semi-rigid bones in the direction of the posterior margins formed by membrane alone ; they are mobile and elastic throughout, and admit of being flexed or folded during the up stroke, and stretched out or extended during the down stroke.

§ 451. The Wings of Pterodactyls, Bats, and Insects supply good Models for Winged Flying-machines.

It is difficult to realise the rate of speed attained by the largest flying reptiles. A pterodactyl, with a stretch of wing of 18 feet, must have flown at a phenomenal pace. In some respects the pterodactyls form the best models for flying-machines. Their wings, supported by the arms, greatly elongated fifth fingers, legs, and more or less elongated flexible tail, resemble beautiful triangular kites, and display a comparatively very large sustaining surface, disposed in the most economic and effective way. As the elevating and propelling parts of the wing are blended with the parachute or sustaining parts, all the advantages possible in flying wings are secured.

The pterodactyls, as explained, belong to the Mesozoic period. They are found in the lithographic limestone of Solenhofen, Bavaria ; the fine mud from which this limestone is originally produced supplying the delicate medium necessary to preserve the thin and consequently perishable flying membrane. Fortunately this mud has been the means of preserving other delicate structures and substances, such as the wings of insects, the bodies of jelly-fishes, &c.

The pterodactyls have been found in considerable numbers, and almost all the large museums possess specimens. The Natural History Department of our own British Museum has been fortunate in this respect, and I have examined with great interest its largest specimen, which (as I have already indicated) has an expanse of wing of 18 feet. It is, from every point of view, a striking and impressive object, as it demonstrates that wings may, in all probability, be indefinitely increased in size, and made to carry great weights. The wing of the gnat and that of the pterodactyl are, as regards area, separated by an immense gulf, yet perfect flight can be attained by both.

EXTINCT PLANTS AND ANIMALS, THEIR PECULIARITIES, LARGE SIZE, RELATIONS TO THE YOUNG EARTH, &c.

There is a great consensus of opinion, especially amongst physicists and mathematicians, that our planet, both during its formation and since it assumed its present spherical shape, has undergone extraordinary changes.

At first it was without form and void, and consisted of diffuse nebulous matter in a highly inflammable condition. The same is to be said of the other heavenly bodies which were being formed at the same time and which constitute our universe.[1]

The earth is part of a system of which the sun is the centre. The nebulous material from which it, and the heavenly bodies generally, were built up was made to run together and coalesce in certain localities ; or centres of attraction were formed in certain spots which drew the nebulous substance in varying degrees to certain regions where differentiation was going on. In all this, attraction and repulsion, cohesion and adhesion, condensation and rarefaction, and various other physical forces took part. The aggregation of the nebulous matter formed what were virtually nuclei on a grand scale. Complicated movements and quite a phenomenal degree of heat were engendered. The original aggregations of nebulous material, the formation of cosmic nuclei, and the mutual attractions exerted by the finer and the grosser bodies, produced movements of various kinds. The chief movements were due to attraction, and the earth as a huge magnet attracted and influenced all lesser bodies in its vicinity, and was itself attracted and influenced by greater bodies outside of itself, especially the sun. The earth, when once formed and in motion, rotated on its axis every twenty-four hours, and produced the phenomena of day and night. It also careered round the sun, following an elliptical course, once a year or every 365 days, and produced the no less striking phenomena of the seasons. The importance of day and night and the seasons to plants and animals cannot be overestimated. They insure the necessary degree of activity and repose and the varying amount of heat and moisture required for both.

What chiefly concern us in the present instance are the movements, the heat, and the moisture. All three are connected with the production of climate, and climate had much to do with the production of life, and with the great extinct races of plants and animals.

At the dawn of creation, the earth was too hot to admit of the presence of moisture in any form. There were no seas, lakes, or rivers. There was, moreover, no atmosphere in the ordinary sense. Water and an atmosphere had to be created before our globe was a fit habitation for living things, whether plants or animals. After prodigious lapses of time the cooling process had reached a point where water, moisture, and an atmosphere were possible. The atmosphere was warm, steamy, and surcharged with carbonic acid ; conditions which favoured, in an eminent degree, a rank, luxuriant vegetation such as prevailed in early geologic times.

Creation was a progressive work—each stage of the process preparing the way for subsequent stages. The Creator from the outset aimed at producing a perfect whole, and every part was made to fit and dovetail into other parts especially constructed to receive them. Design was writ large at every step. Nothing occurred in a haphazard way or by chance. Law and order everywhere prevailed, and regulated the composition, size, shape, and movements of the smallest and largest bodies. Nothing clashed, and elaborate preparations were made for the advent of plants and animals, and especially man, on the earth.

The successive stages of the creation of our planet and its inhabitants can readily be traced. The earth had not only to be made, it had also to be cooled down before the work of creation could be proceeded with. The time

[1] The nebulous matter, whatever its consistence, cannot be regarded as fundamentally simple in composition. It has in it in some form (actual or potential) all the elements of the young earth and the other heavenly bodies. It is necessary to be quite clear upon this point, as certain physicists and physiologists, of late years, have done their utmost to create the impression that the inorganic and organic kingdoms are produced from a perfectly simple matrix identical in all its parts and particles. If this were true, it would follow that the seventy odd elements composing the earth could have no existence, and plants and animals which are known to differ fundamentally from each other would be an impossibility. From a substance absolutely identical in ultimate composition only one body (dead or living is immaterial) can be produced. A mixture, however intimate and perfect it may be, consists of parts, and these parts are never precisely alike. These remarks apply to gases, fluids, semi-solids, and solids. The atmosphere and water, although popularly considered simple, are not really so. The same is true of molten and kindred masses, however high their temperatures. Proofs of these points in the inorganic kingdom are to be obtained by chemical analysis and by the employment of the spectroscope and microscope. In the organic kingdom the proofs are less direct, but equally convincing. Plants and animals only reproduce themselves ; a fish does not produce a reptile, a reptile a bird, or a bird a mammal, neither do plants produce animals nor animals plants ; all which goes to show that the reproductive elements of plants and animals, although apparently simple and identical, are highly complex, and differ widely from each other. In other words, the differentiation which is such a marked feature of plants and animals is provided for (potentially or otherwise) in the sexual elements themselves. They can only develop on lines laid down for them from the first. Similar remarks apply to the heavenly bodies. If these differ in constitution it is because due provision was made for their so doing from the outset. Those who maintain that the inorganic and organic formative matter is simple are obliged to admit the existence of a directing Power behind and beyond the formative matter which is highly complex in its operations and in no sense simple.

The composition, shapes, sizes, and movements of plants and animals and of the heavenly bodies are equally the outcome of design and of a general plan.

occupied by the cooling process was incredibly great—so great that the imagination utterly fails to realise it even partially.

The creative preliminaries over, the soil (the product of the dry land) was next prepared to receive plants. In them life, the crowning event of creation, first made its appearance. Plants form the natural food of animals, and when they were established upon the earth the pabulum of animals was assured. Animals cannot live directly upon inorganic matter. Inorganic substances must be reduced and prepared by plants before they can be appropriated as food by animals. The pre-existence of plants was necessary to the advent and continued existence of animals.

Animals were created subsequently to plants, and gradually overran the whole earth. The last animal to be formed was man, and he is the avowed master of everything that lives.

The plants and animals created were typical, and the seed of each was in itself, and produced only its own kind. Plants and animals were also created in an ascending series and formed types—the higher animals being the last to be produced.

The plants and animals were created for special periods and for special regions ; those of early primeval times essentially differed from those of modern times. The primeval plants differed from modern ones as regards size and type and their extraordinary growth and profusion ; and the primeval animals differed from their modern congeners in their bizarre shapes and their proverbially large size. The condition of the earth and the atmosphere in the infinitely remote past quite accounted for the peculiarities referred to. The warm earth and its steamy hot atmosphere abounding in carbonic acid were admirably adapted to the production of a rich, rank, superabundant vegetation. The presence of such a vegetation in turn favoured the production of a giant race of animals.

It is the early plants and animals, long since extinct and now known as fossil, that I propose to discuss very shortly in the present connection.

While the extinct plants were larger as a whole than modern ones, none of them could compare in size with the modern Sequoia (*S. gigantea*).[1] Similarly, the run of extinct animals was larger than that of modern animals, although none, the great fossil shark (*Carcharodon megalodon*) perhaps excepted, approached in size the largest modern whales.[2]

The great races of plants and animals came unheralded, and, with the exception of the fossil remains of some of them, have passed away unrecorded. They had no known ancestors and they have, for the most part, left no recognisable progeny. It is important to be quite clear on this point, as "evolutionists," and those who advocate the origin of species by means of "natural selection," claim continuity in plants and animals which does not exist. The breaches in continuity cannot be bridged over ; the missing links have never been, and there are good grounds for believing never will be, found. This one circumstance vitiates and renders of none effect the many elaborate and ambitious tables of descent which take for granted that every living thing sprang from one or from a very few common ancestors. If whole cycles of great plants and animals can come and go without, in many cases, even leaving a trail, it is vain to assert, in the absence of direct proof, that every plant and animal is manufactured out of some pre-existing plant and animal, or, as it is theoretically but confidently put, "evolved."

The existence in time and space of distinct races of large plants and animals did not preclude the contemporaneous existence of innumerable humble plants and animals, even to the lowest. These had their place in the great scheme of creation, just as the more advanced ones had, but there is nothing to show that the smaller forms of plants and animals were in any way connected with the production of the larger and more noble forms. Curiously enough, the lower forms in geologic time were, in not a few instances, more complex, and occupied a higher platform, than do those of the present day.

All that can certainly be said of the progression from lower to higher forms is that plants and animals are arranged in an ascending series as types. This, however, is a very different thing from asserting that man was manufactured by a process of evolution, by endless modifications in infinite time, from an oyster or even a much lower form. The sequence and gradation in creation bespeak intelligence and design on the part of the Creator, but do not prove the existence of evolution as a factor in creation.

The most striking feature in the great races of plants and animals which have passed away is their wide distribution on the earth's surface. They are found in the arctic, the temperate, and the torrid zones, and indicate that the plants and animals have changed less themselves than the climates which characterise the march of the ages. In

[1] The *Sequoia gigantea* is the largest of modern trees. It is found only on the western slope of the Sierra Nevada mountains at an elevation of from 4000 to 6500 feet. It attains a height of 400 feet, or thereby, and has a girth of from 70 to 90 feet. One recently discovered had a base circumference of 109 feet. The tree is pyramidal-shaped, and the first branches occur about 100 feet from the ground. It is said to live to an enormous age, anything from 5000 to 8000 years. The last statement has to be received with caution, although partly confirmed by the number of the rings of growth.

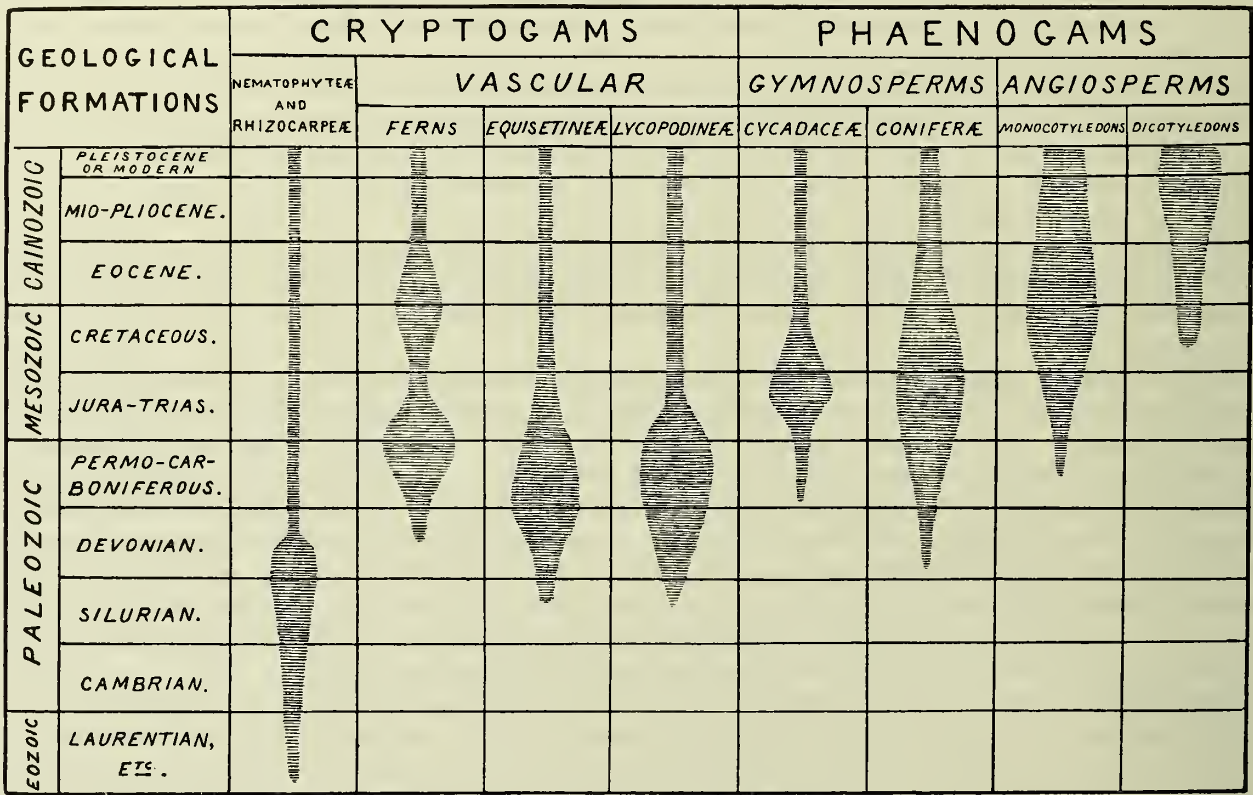
[2] The three largest modern whales are the rorqual (*Balænoptera physalus*), the right whale (*Balæna mysticetus*), and the sperm whale (*Physeter macrocephalus*). The first is distinguished by its length the second by its great girth and the third by its huge head and the possession of teeth. The rorqual attains a length of 100 feet or so, and the sperm whale has, generally, a length of 80 feet.

other words, fossil remains of plants and animals are found in arctic and temperate zones which must have had a tropical origin, while plants and animals are found in tropical regions which must have had an arctic or temperate origin.

This much may be predicated with certainty. If separate creations of one or a very few typical plants and animals are admitted in past geologic time (and they cannot well be denied) there is no reason why separate creations may not occur at any period in the world's history. Many advanced thinkers hold firmly to this view. If creation be regarded as a progressive, rather than a finished work, the breaches in continuity and the absence of "missing links" in plants and animals would be set at rest once and for all.

The evolutionists ignore or forget the fact that advanced races of plants and animals occasionally disappear, and are followed by races of inferior plants and animals. This is not evolutionary advance, but retrogression. They also forget that there are parasitic plants and animals which, instead of advancing, deteriorate. These also furnish examples of retrogression.

They further overlook the circumstance that even in the highest animals the impregnated reproductive cells liquefy, fuse, and break up into elementary molecules and atoms; in other words, retrogress before they take final



shape in specific directions to form particular animals. Lastly, they fail to realise that development in its several forms is not one continuous growth, but growth suppressed or retarded in one direction, and quickened and encouraged in another, and, it may be, opposite direction. The hands of the clock do not always move in the forward direction. They are sometimes stopped, and sometimes even set back, but everything is done under supervision and under law and order when the final result is taken into account. We have examples of this in the curiously modified foot of the horse, the wing of the bird, and the wing of the bat and pterodactyl. It is this variety of growth, stasis, retrogression, and partial or complete absorption of parts already formed which gives rise to the so-called vestiges or remnants in animals on which evolutionists place so much reliance, as proving the accuracy of their favourite doctrine.

It should be stated in this connection, that in the development of the higher animals *in utero*, several associated parts are growing simultaneously, other parts growing separately and independently; while others have ceased to grow, or are actually retrogressing and undergoing active absorption. We have thus five conditions in the development of the fœtus: (*a*) active and simultaneous growth; (*b*) separate growth; (*c*) stasis of growth; (*d*) retrogression and disintegration; (*e*) absorption and disappearance of parts already formed. There is not the steady uniform advance in the growing parts which evolution implies. There is, however, a state of things in which design and intelligence of the highest order can be clearly traced. The several parts of the young animal are prepared in

advance of the time when they are called upon to act—structure preceding function—but function and structure being so accurately adjusted that all the parts not required are eliminated prior to or soon after birth. It is the adult or completed animal which represents the type, and not the young or growing animal. It is safe to conclude that the development of the young animal *in utero* affords no proof of evolution.

§ 452. Extinct Plants—their Unusual Appearance, &c., as compared with Modern Plants.

The great extinct races of plants and animals may be left to tell their own tales.

The plants fall first to be considered. Sir W. Dawson in his "Geological History of Plants" has furnished a table which gives in a succinct and instructive form a list of the great extinct plants, the approximate time of their appearance and disappearance, and the period at which they attained their greatest development or zenith. I append the table in question (p. 1298).

A glance at the above table shows that the extinct fossil plants had a beginning when they were few in number, a period of increase, a period of decrease, and a period of decay and disappearance.

Sir William gives another table in which the animals contemporaneous with the plants are set forth, and which likewise is of great value. It is, in a sense, supplemental to the table dealing with plants, and is given below.

Animals.	Systems of Formations.		Plants.
Age of Man and Mammalia	Cainozoic	Modern Pleistocene Pliocene Miocene Eocene	Angiosperms and Palms dominant.
Age of Reptiles	Mesozoic	Cretaceous Jurassic Triassic	Cycads and Pines dominant.
Age of Amphibians and Fishes Age of Invertebrates	Palæozoic	Permian Carboniferous Erian Silurian Ordovician Cambrian Huronian (Upper)	Acrogens and Gymnosperms dominant.
Age of Protozoa	Eozoic	Huronian (Lower) Upper Laurentian Middle Laurentian Lower Laurentian	Protogens and Algæ

A study of the second, and, in a way, the more comprehensive table, shows that the several orders of animals lived at those precise periods when their peculiar kind of food was most abundant; the great races of animals being contemporaneous with the great races of plants. All this bespeaks intelligence and design in the past, which cannot be ignored or set aside by any mechanical theory of the origin of the universe, however plausible.

The tables given above are supposed to cover a period of 200,000 years, provided the modern period covers 10,000 years, and is taken as a standard for the other periods.

It is exceedingly difficult even approximately to estimate geologic time. In Dana's opinion "the time ratios for the first three great ages may be as one for the Cainozoic to three for the Mesozoic and twelve for the Palæozoic." According to Hall and Houghton the ratios are: Azoic, 34·3 per cent; Palæozoic, 42·5 per cent; Mesozoic and Cainozoic, 23·2 per cent. The modern period is regarded as much shorter than the others of the Cainozoic, from which it follows that the tables may have to be measured by millions of years instead of thousands.

The geologic periods of greatest interest as far as the great plants and animals are concerned are the Palæozoic, Mesozoic, and Cainozoic—the first including Acrogens and Gymnosperms among plants, and the amphibians and fishes among animals; the second embracing the Cycads and Pines among plants, and the reptiles among animals; and the third, and most modern, containing the Angiosperms and Palms among plants, and the mammals and man among animals.

"In the Palæozoic age, the club-mosses, ferns, and horse-tails engrossed the world, and grew to sizes and attained degrees of complexity of structure not known in modern times."

The fishes in the Palæozoic period in some cases attained enormous dimensions.

The great extinct Miocene shark (*Carcharodon megalodon*) was believed to be 100 feet in length. This conclusion has been arrived at by a comparison of the teeth of the extinct form with those of the largest living sharks. These great teeth, found in admirable preservation in Suffolk, England; in Maryland, United States of America, and in Malta, are three times as large as those of the biggest living sharks.

Professor Sir E. Ray Lankester[1] has given a photograph of the jaws of one of the largest of recent sharks (*Carcharodon rondeletii*), 30 feet long, with the teeth *in situ*, as preserved in the Natural History Department of the British Museum, London, from which it appears that the teeth of the extinct monster (*Carcharodon megalodon*) are, as nearly as may be, three times the size of the *Carcharodon rondeletii*.

The fossil shark teeth are 6 inches in length; those of the Museum specimen only 2 inches. As the gape of the jaws of the modern shark is 2 feet, that of the great extinct shark must have been 6 feet. It is difficult to realise, even in imagination, a shark with a gape of 6 feet (*vide* Fig. 540).

Mixed up with the teeth of the great extinct shark are numerous examples of the strange spiral structures known as coprolites, which long remained a puzzle to palæontologists. The coprolites are, in reality, the excreta of the shark, and indicate that the extinct forms, like the modern ones, had a spiral intestine. They are found, on microscopic examination and analysis, to consist largely of partially digested fish bones and débris, especially the former.

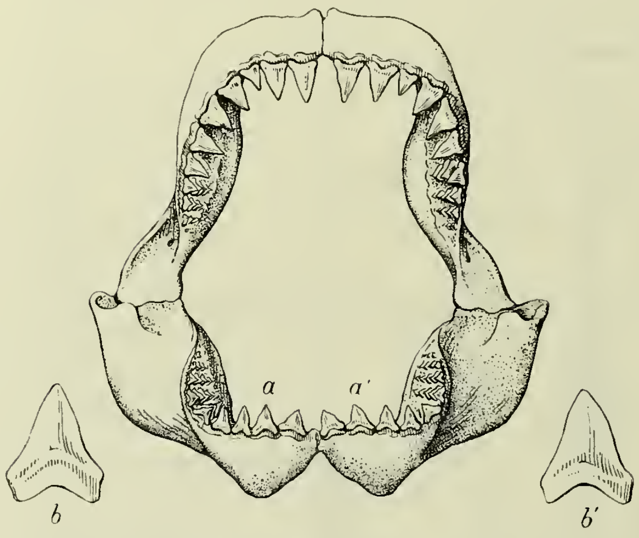


FIG. 540.—Photograph of the jaws of a large recent shark (*Carcharodon rondeletii*), showing the teeth (*a*, *a'*). At *b*, *b'* is placed a single tooth of the great extinct Miocene shark (*Carcharodon megalodon*) for comparison. The largest of the recent teeth is 2 inches in length, the fossil teeth are 6 inches in length (after Lankester).

Other examples of fossil spiral formations are not uncommon. Magnificent examples of spiral structures are seen in the nautilus, the ammonites (some of which latter have a diameter of 5 feet), and other shell fish. They also occur in the tusks and limbs of the mammoth, American mastodon, and other large extinct animals.

Similar remarks are to be made of extinct plants. In these there are spiral cells, spiral seeds and fruit, spiral fronds, spiral roots, spiral branches, spiral arrangements of leaves, markings, &c., all which go to prove that while the extinct plants and animals, in many cases, markedly differ from existing plants and animals, the fundamental lines on which they are built up have not materially altered. The spiral arrangements of extinct and living plants and animals show this pretty conclusively.

Sir J. William Dawson makes the following general statement regarding the order and succession of plants on the earth: "There is a certain rough correspondence between the order of rank of plants and the order of their appearance in time. The oldest plants that we certainly know are algæ, and with these there are plants apparently with the structures of thallophytes but the habit of trees, and which, for want of a better name, I may call *Protogens.* Plants akin to the rhizocarps also appear very early. Next in order we find forests in which gigantic ferns and lycopods and horse-tails predominate, and are associated with pines. Succeeding these we have a reign of gymnosperms, and in the later formations we find the higher phænogams dominant. Thus there is an advance in elevation and complexity along with the advance in geological time, but connected with the remarkable fact that in earlier times low groups attain to an elevation unexampled in later times, when their places are occupied with plants of higher type."[2]

Perhaps the most interesting period of extinct fossil plants is that connected with the formation of graphite, anthracite, and coal.

Graphite or plumbago occurs in the Laurentian age, and in later ages we have deposits of coal due to the accumulation and slow putrefaction of masses of vegetable matter. Further, it has been found that where the coal formations have been exposed to igneous action, the coal is converted into anthracite and graphite, and the bituminous shales into graphite shales.

"When Palæozoic land-plants have been converted into graphite, they sometimes perfectly retain their structure.

[1] "Extinct Animals," 1905, pp. 264, 265, Figs. 192, 192 (a).

[2] Op. cit. p. 7.

Mineral charcoal, with structure, exists in the graphitic coal of Rhode Island. The fronds of ferns, with their minutest veins perfect, are preserved in the Devonian shales of St. John, in the state of graphite ; and in the same formation there are trunks of Conifers (*Dadoxylon ouangondianum*) in which the material of the cell-walls has been converted into graphite, while their cavities have been filled with calcareous spar and quartz, the finest structures being preserved quite as well as in comparatively unaltered specimens from the coal-formation."

Sir J. W. Dawson introduces us to the plants of the coal formation in the following picturesque passages :—"Ascending from the Erian to the Carboniferous system, so called because it contains the greatest deposits of anthracite and bituminous coal, we are still within the limits of the Palæozoic period. We are still within the reign of the gigantic club-mosses, cordaites, and taxine pines. At the close of the Erian, there had been over the whole

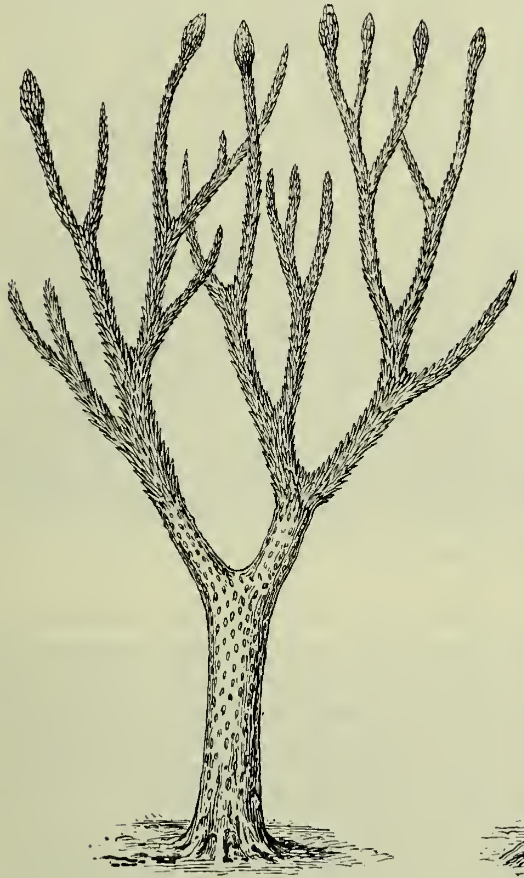


FIG. 541.

FIG. 542.

FIG. 543.

FIG. 541.—*Lepidodendron corrugatum*, a tree characteristic of the Lower Carboniferous period (Dawson).
FIG. 542.—*Sigillariæ*, restored. To left, *Sigillaria brownii*. To right, *Sigillaria elegans* (Dawson).
FIG. 543.—*Lepidophloios acadianus*, a lepidodendroid tree of the coal-formation (Dawson).

northern hemisphere great changes of level, accompanied by active volcanic phenomena, and under these influences the land flora seems to have much diminished. At length all the old Erian species had become extinct, and their place was supplied by a meagre group of lycopods, ferns, and pines of different species from those of the preceding Erian. This is the flora of the Lower Carboniferous series. But the land again subsided, and the period of the marine limestone of the Lower Carboniferous was introduced. In this the older flora disappeared, and when the land emerged we find it covered with the rich flora of the coal-formation proper, in which the great tribes of the lycopods and cordaites attained their maxima, and the ferns were continued as before, though under new generic and specific forms. There is something very striking in this succession of a new plant world without any material advance.

"Conveying ourselves, then, in imagination forward to the time when our greatest accumulations of coal were formed, and fancying that we are introduced to the American or European continent of that period, we find ourselves in a new and strange world. In the Devonian age, and even in the succeeding Lower Carboniferous, there

was in the interior of America a wide inland sea, with forest belts clinging to its sides or clothing its islands. But in the coal period this inland sea had given place to vast swampy flats, which, instead of the oil-bearing shales of the Erian, were destined to produce those immense and widespread accumulations of vegetable matter which constitute our present beds of bituminous and anthracite coal. The atmosphere of these great swamps is moist and warm. Their vegetation is most exuberant, but of forms unfamiliar to modern eyes, and they swarm with insects, millepedes, and scorpions, and with batrachian reptiles large and small, among which we look in vain for representatives of the birds and beasts of the present day.

"Prominent among the more gigantic trees of these swampy forests are those known to us as *Sigillariæ* (Fig. 542). They have tall, pillar-like trunks, often several feet in diameter, ribbed like fluted columns, but in the reverse way, and spreading at the top into a few thick branches, which are clothed with long, grass-like leaves. They resemble in some respects the Lepidodendra of the Erian age, but are more massive, with ribbed instead of scaly trunks, and longer leaves. If we approach one of them more closely, we are struck with the regular ribs of its trunk, dotted with rows of scars of fallen leaves, from which it receives its name *Sigillaria*, or seal-tree. If we cut into its stem, we find that, instead of the thin bark and firm wood with which we are familiar in our modern trees, it has a hard external rind, then a great thickness of cellular matter with rope-like bands of fibres, constituting an inner bark, while in the centre is a firm, woody axis of comparatively small diameter, and somewhat intermediate in its structure between that of the Lepidodendra and those of the cycads and the taxine conifers. Thus a great stem, five feet in diameter, may consist principally of cellular and bast fibres with very little true woody matter. The roots of this tree are perhaps its most singular feature. They usually start from the stem in four main branches, then regularly bifurcate several times, and then run out into great cylindrical cables, running for a long distance, and evidently intended to anchor the plant firmly in a soft and oozy soil. They were furnished with long, cylindrical rootlets, placed regularly in a spiral manner, and so articulated that when they dropped off they left regular rounded scars. They are, in short, the *stigmariæ*, which we have already met with in the Erian."

As illustrating the points indicated I append figures of *Sigillariæ* (*brownii* and *elegans*), *Lepidodendron corrugatum*, and *Lepidophloios acadianus*, prominent trees of the coal formations. To these have to be added large numbers of splendid ferns, horse-tails (*Calamites*) and other plants, and an inconceivable quantity of spores, spore cases, fruits, &c.

The trees referred to markedly differ from existing trees, and belong to a previous order of things in which modern vegetation can scarcely be said to take a part.

The value of coal and of iron, usually associated with it, to civilised man cannot be over estimated. This remarkable substance, when ignited, gives out heat and light and power, and cheers and brightens countless millions of homes on all parts of the earth's surface. It restores the warmth and light which it abstracted through the plant from the sun and the atmosphere in the far-off Palæozoic age. It is an untold blessing to modern man, but it was also, during its formation, the means of making contemporary animals comfortable, by depleting the atmosphere of its excess of poisonous carbonic acid which might have proved fatal to them. In its advent and dissolution by burning it has been an unmixed good, and many are disposed to see in it one of the crowning examples of design on the part of the Creator in His beneficent treatment of man.

Nor does the matter end here. The indulgence of the Creator to unborn man will not terminate with the exhaustion of the much prized coal. So long as the sun and the earth, and the waters of the earth, and the clouds and the atmosphere endure, so long will the creature comforts of the race be assured. Already electricity, the product of the waterfalls and tides and moving air, is coming to the front, and with it a new and apparently endless supply of heat, light, and power. The possibilities of electricity cannot be even approximately estimated. It promises to become the universal power of the future—a power which can warm the home, supply heat for cookery, convey a message, drive a car, propel a boat, and actuate anything and everything in the shape of machinery.

It may be interesting and instructive if I here give characteristic representations of the several geologic periods and their extinct flora. This is done in Plate clxxviii.

PLATE CLXXVIII

FIG. 1.—Silurian vegetation restored. *Protannularia, Berwynia, Nematophyton, Sphenophyllum, Arthrostigma, Psilophyton.*

FIG. 2.—Vegetation of the Devonian period, restored. *Calamites, Psilophyton, Leptophleum, Lepidodendron, Cordaites, Sigillaria, Dadoxylon, Asterophyllites, Platyphyllum.*

FIG. 3.—Jurassic vegetation. Cycads and pines (after Saporta).

FIG. 4.—Vegetation of the Later Cretaceous. Exogens and palms (after Saporta).

PLATE CLXXVIII

Fig. 1.

Fig. 3.

Fig. 2.

Fig. 4.

It will have been observed that animals appeared on the earth soon after the plants, and since the formation of the plants and animals they have been closely associated. Plants purify the air for animals and form their food. There are, however, among animals carnivora or flesh feeders, which kill and eat each other. I mention this circumstance because when we come to speak of the great extinct reptiles and mammals we shall find not only herbivora or plant feeders, but also carnivora or flesh feeders. In the geologic period, long before the advent of man on the earth, death was a prominent factor in the great scheme of life. The herbivora or plant feeders kill plants for food in the same sense that the carnivora kill animals for food.

It is well to recognise the fact that the death of plants and animals is a necessity in the great round of existence, and is, in no way, the product of sin. In these remarks I, of course, speak of physical death and not of spiritual or moral death, which falls under quite another category. The former applies to plants and animals; the latter to man, and man only.

In addition to the herbivora and carnivora, there are the omnivora or mixed feeders, which live upon plants and animals alike.

The countless millions of spores, seeds, fruits, and young animals in excess of those required to keep up the original stock go directly to the maintenance of animals, whether carnivora or omnivora. The natural death, and inevitable decay after death of animals, in due course contribute to the nourishment of plants. There is a ceaseless round of death and life in the physical universe, and this state of things has always prevailed, and prevails now.

When I speak of the great extinct races of plants and animals I do not mean to assert that there are no great plants and animals in the present day. That would be misleading. All I wish to convey is that in certain geologic epochs the size of the majority or common run of plants and animals was decidedly larger than in modern times.

Recent fish cannot match the great extinct sharks, and recent reptiles are dwarfed by the huge fossil reptile, the Atlantosaurus, the thigh-bone of which measured over six feet in length; the animal itself being a third bigger than the largest elephant. In like manner no modern bird comes near the size of the extinct Phororachus, or the great extinct moa, the thigh-bone of which is much larger and stronger than the thigh-bone of a horse. Neither can our largest living quadruped, the modern elephant, be pitted as to size against the mammoth and mastodon. Similarly, the modern bat is rendered insignificant by the huge extinct flying reptile—the pterodactyl—with a stretch of wing of twenty or more feet.

In dealing shortly with the great extinct fishes, reptiles, birds, and mammals it is not necessary to do more than mention the existence in geologic time of a large number of small animals and humble animal forms. It is sufficient to state that the lower animal forms then (as now) could be counted by thousands and probably by millions. At no period in the history of our globe, from the time it became habitable, were they excluded. The presence and predominance of the great fauna did not militate against the presence of the lesser fauna. Both were necessary to the original scheme of creation.

It will be convenient to take up the great extinct animals in the following order, namely, the fishes, fish-reptiles, reptiles, birds, and mammals.

The primeval fishes presented all kinds of curious forms. They were, in many cases, armoured—their scales being very thick and presenting the appearance of a coat of mail. Their fins were also peculiar—the tail fin being generally more or less unsymmetrical or heterocercal. Their habits must have been sluggish and their power of swimming limited as compared with modern fishes. I give a representation of three of them at Plate clv. Fig. 6, A, B, C, p. 1166.

I also give a figure of one of the sharks. This fish is remarkable for its enormous fins and powerful heterocercal tail. It is a veritable greyhound of the ocean. Its huge fins cause it to resemble a ship in full sail (Plate clv., Fig. 1, p. 1166).

The extinct fish-reptiles are represented by the Plesiosaurus and Ichthyosaurus. I give descriptions and delineations of careful original restorations of these at Figs. 361 to 366 inclusive, pp. 1108 and 1109; also at Plates clxiii. and clxiv., pp. 1187 and 1189.

§ 453. Gigantic Extinct Reptiles and Birds.

The extinct reptiles deserve a more than passing notice alike because of their antiquity, great size, bizarre shapes, numbers, and wide distribution. Their remains have been found in Europe, Africa, India, America, and Australia. They were the chief representatives of life during the Triassic and Jurassic ages, and were mainly herbivorous, and fed on the succulent stems, shoots, branches, leaves and roots of the most abundant and richest vegetation the world has yet seen.

According to Dr. Mantell the localities inhabited by the Dinosaurs were rich in conifers, ferns, cycads, palms, and horse-tails and similar plants of large size, which grew in great profusion.

The carnivorous reptiles, of which there were several, found in the herbivorous reptiles, and in contemporary animals, a practically unlimited supply of flesh food. The prevalence of a superabundant vegetation in part accounts for the excessive growth and colossal size of the herbivorous reptiles, and the great numbers and size of the latter largely explain the enormous dimensions of the carnivorous reptiles. The extinct herbivorous and carnivorous reptiles were characterised by small heads and brains, long, flexible, powerful necks, huge tapering tails, small anterior and large, singularly well developed posterior extremities (Fig. 544, *Scelidosaurus harrisoni*). They inhabited, for the most part, deep valleys through which flowed sluggish streams with soft mud banks ; also marshy flats abounding with lagoons. They preferred oozy, moist localities covered with tall rank grasses, reeds and trees, chiefly

FIG. 544.—An armoured Dinosaur (*Scelidosaurus harrisoni*).

ferns, in which they could conceal themselves and feed securely. They were, as a rule, lazy, luxurious animals, and spent the greater part of their time in eating and sleeping—two prime requisites for an excessive growth of soft and hard tissue. They revelled in a plentiful supply of moisture, and there are good grounds for believing that they spent a considerable portion of their lives actually in the water. The possession of a long, flexible neck, and of a huge and no doubt powerful swimming tail, favours this belief. Their long, mobile necks would enable them to grub up juicy aqueous plants from the bottom of the rivers, lagoons, &c., with dexterity and ease. Indeed the inordinate length of the neck and tail can only be adequately accounted for on the supposition that they led a semi-aquatic existence. The long neck and tail were better adapted for an aquatic than a terrestrial life. That they took refuge in the water when pursued by enemies can scarcely be doubted. The long, ponderous tail was equally useful as a swimming organ, and as a supporting organ on marshy, treacherous mud flats. It naturally lent itself, in conjunction with the powerful hind limbs of the reptiles, to raise the body in a semi-erect position when they stretched their long necks and were browsing on the top branches of ferns and allied forms of vegetation. The feet of the reptiles were of themselves too small to afford adequate support on the oozy, spongy land they frequented. In the majority of cases, as indicated, the anterior feet and limbs were small and dwarfed as compared with the posterior feet and limbs,

This had the effect of throwing the centre of gravity far back, and of keeping it low in the reptiles—a state of matters which was emphasised when they assumed the semi-erect position. Some of the reptiles occasionally walked as bipeds, and carried the huge tail free of the ground. This required an unusual degree of exertion, and could only be indulged in for short periods.

The modern crocodiles, lizards, and newts considerably resemble in general appearance the extinct reptiles, but in them the neck is short, the head large, and the anterior and posterior limbs pretty equally developed. The tail is long, but no provision is made for the animals assuming a semi-erect position. Moreover, the weight of the crocodile, lizard, and newt is trifling as compared with that of the ponderous extinct reptiles, some of which weighed as much as twenty tons. The marshy, yielding land would, without difficulty, support the smaller animals, but would hopelessly mire the gigantic reptiles. The long tails of the former would not be required to give support to the body; whereas in the latter they would be more or less indispensable. It is true that in the megatherium, or great extinct land sloth (*Megatherium americanum*, Fig. 545), found in the Pleistocene gravels in S. America, and in the kangaroo (*Macropus major*) and marsupials generally, the tail is enormously developed, but in these a distinct and special caudal function can be traced. In the megatherium the tail and hind legs support the animal when cropping tall branches, leaves, fruits, tender bark, &c. In the kangaroo and its congeners the tail and hind legs afford support and a powerful leaping apparatus.

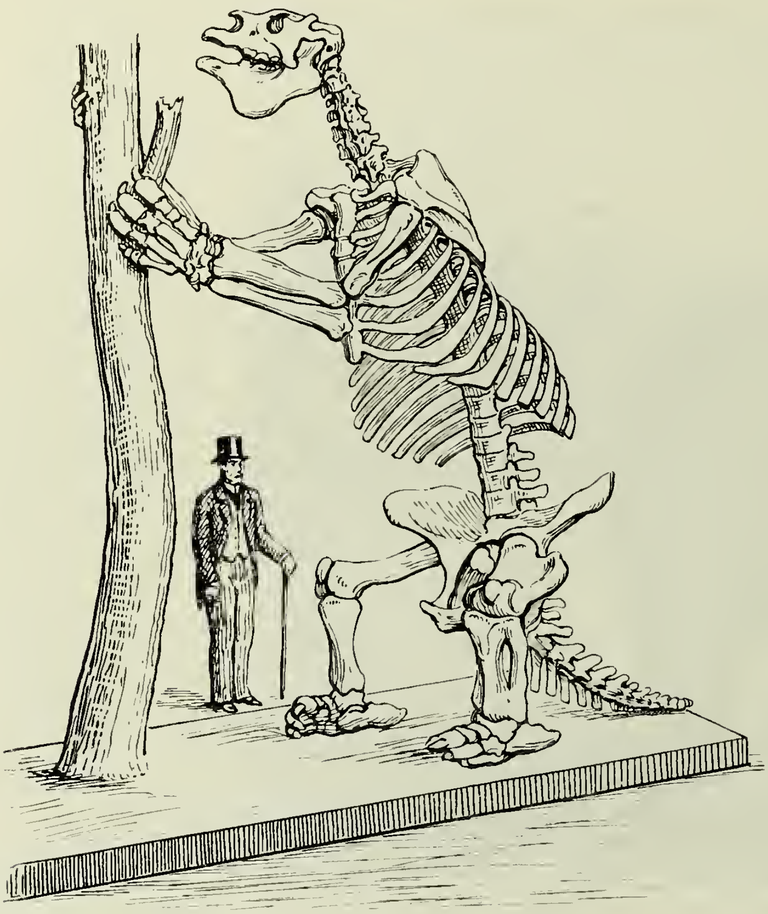


Fig. 545.—*Megatherium americanum.*

It is impossible to adapt the great extinct reptiles to any modern scheme of classification. They are typical animals, confined to particular periods of the earth's history, namely, the Triassic and the Jurassic.

Some zoologists have endeavoured to show that they are descendants of the crocodiles on the one hand, and the progenitors of the birds on the other. They base their theories on the structure of the bones, which are light, spongy, and contain air instead of marrow, unless in the case of some of the long bones. The hollow bones are a feature of the extinct reptiles, and of modern crocodiles and birds. They also trace resemblances in the pelvic bones, the claws of the anterior and posterior extremities, the presence of teeth, the laying of eggs, the length of the necks and tails, &c.

The distinctions in question are not constant or valid. The crocodiles have large heads, biggish brains, short necks, and long tails. They are never herbivorous. Their fore and hind legs are pretty equally developed. The birds have sometimes solid bones, and are provided with feathers which form a special and characteristic covering for the body; they very rarely possess teeth; they have in many instances, but not always, long necks; their tails, as a rule, being short. Above all, they are warm-blooded, and have hearts consisting of four cavities; peculiarities which get rid of the mixed circulation of reptiles and of cold-blooded animals generally. Professor Huxley especially endeavoured to connect the extinct reptiles or Dinosaurs with the great running birds—the moa, ostrich, &c.—through their pelvic bones and greatly developed posterior extremities. A representation of the skeleton of the moa (*Dinornis maximus*) is given at Fig. 546, p. 1307. In this figure the great height of the moa is contrasted with the modern ostrich and with man according to scale. This gigantic bird is found in the "alluvial" deposits of New Zealand. He regarded the Dinosaurs as the remote ancestors of birds. Professor Owen, on the other hand, considered the resemblances as accidental, and in no way implying relationship. Professor Seeley went further, and gave it as his opinion that the Dinosaurs were not reptiles in the ordinary sense, and

that they formed a separate and independent order of animals. With this view I wholly agree. Professor Marsh separated the Dinosaurs from the reptiles in the matter of laying eggs. He combated the idea that the Dinosaurs did lay eggs, and was inclined to regard them as viviparous. The famous Baron Cuvier, the founder of the science of palæontology, associated the great extinct reptiles not with birds but with quadrupeds. He announced what was a startling view in his day, "that there was a period when our planet was inhabited by reptiles of appalling

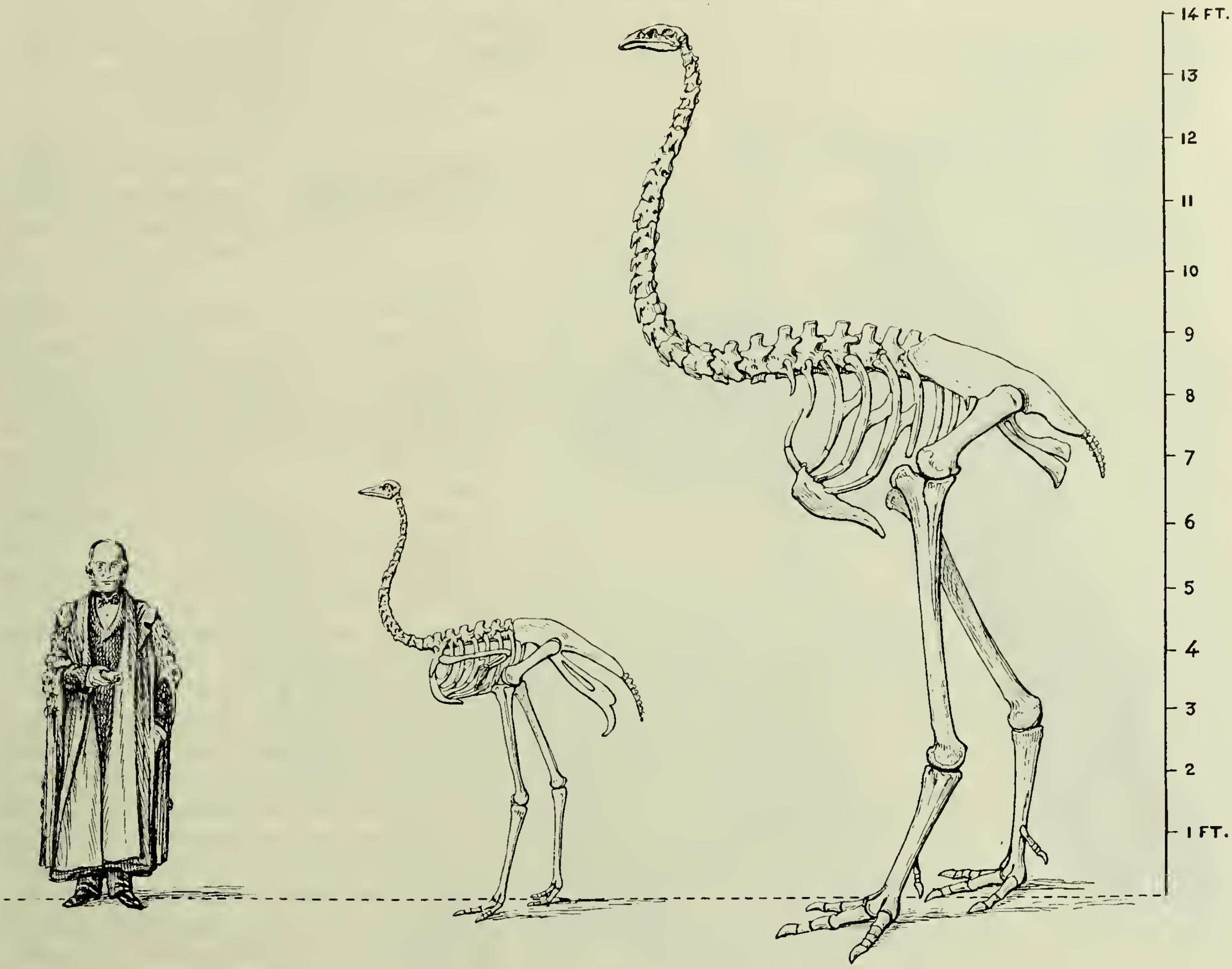


FIG. 546.—Skeleton of the great moa (*Dinornis maximus*).

magnitude with many of the features of modern quadrupeds," and Dr. Mantell speaks of a distinct age of reptiles ;[1] the reptiles being the ruling class among animals.

In one extinct bird, the *Archæopterix siemensi* (Fig. 547, p. 1308), found in the lithographic stone of Solenhofen, Bavaria, teeth, a long osseous tail, and feathers were present. This anomalous creature had also three fingers, each terminating in a claw, and fairly perfect wings. Several birds of this primeval type have now been discovered. If the teeth, which may be regarded as integumentary appendages, be eliminated, the only peculiarities to be considered in classifying the archæopteryx are the long, osseous tail and the three-fingered, clawed wings. The archæopteryx cannot be said to bear a striking resemblance to any form of reptile. As regards the long, osseous tail it may be noted that some of the extinct flying reptiles (pterodactyls) were provided with long tails (*Rhamphorhynchus* and *Dimorphodon*) and others with short tails (*Pterodactylus*). The same is true of the bats. The tail in flying creatures becomes a negligible quantity as a basis for classification.

Instead of regarding the great extinct reptiles as connecting links in the chain of descent, it is better to regard them, with Seeley, as independent types consisting of several distinct orders or families, and confined to a particular

[1] *Edin. Phil. Journal*, 1821.

period of time. They were intermediate types, but they had no ancestors in the ordinary evolutionary sense, neither have they left any direct or recognisable descendants. They were created for a special geological era, and when that era passed away they disappeared.

Professor Huxley, as indicated, did what he could to establish a connection between the extinct reptiles and the birds, and to derive the latter from the former, but his arguments on the subject are neither convincing nor conclusive. Too much importance is attached to isolated and trifling peculiarities which may be variously explained.

Professor Sir E. Ray Lankester,[1] when referring to the archæopteryx, writes as follows: "It cannot be said that this extinct bird goes far towards connecting birds with reptiles; but in the possession of separate claw-bearing fingers, a long bony tail and teeth, in the apparent want of a beak, it does come nearer to lizard-like reptiles than does any other known bird."

Fig. 547.—*Archæopteryx siemensi.*

The great extinct reptiles had as geologic contemporaries the huge so-called fish and sea lizards (Ichthyosaurus, Plesiosaurus, &c.) (Figs. 361 to 366 inclusive, also Plates clxiii. and clxiv.). The great extinct mammals came later.

The history of the colossal extinct reptiles is not so well known as it deserves to be. It dates back only to the first half of last century. To Dr. Gideon A. Mantell is due the great merit of first directing attention to the existence, in geologic time, of a great unknown race of animals, as attested by finds of their teeth and fragments of their bones. He encountered innumerable difficulties at the outset of his investigations in establishing the accuracy of his views, as he had nothing wherewith to compare his fossils. His operations were confined chiefly to England. He had the good fortune to have Baron Cuvier, Professor Owen, and other distinguished palæontologists to consult with, but they could help little, and their explanations were often very wide of the mark. By a lucky chance, when dealing with the teeth of the extinct reptilian monsters, he had his attention directed to the teeth of the iguana, a comparatively small modern lizard (Fig. 548). The dentition of the latter gave him the cue to the solution of the problem which had baffled him and all those to whom it had been referred. He found that the fossil teeth which had so long distracted him were in reality those of great reptiles, and he referred his several finds to the Dinosaurs, and to one in particular which he designated the iguanodon (Fig. 549), literally "iguana tooth." The iguana is a land lizard from three to five feet in length, which inhabits several parts of America and the West Indies. It swallows its food whole, in which respect it differs entirely from the iguanodon, which masticated it after the manner of modern herbivorous mammals. The iguanodon in the matter of mastication cannot be regarded as a reptile pure and simple. "It is the power of perfect mastication possessed by the iguanodon that is so strange, for it implies a most remarkable approach in extinct reptiles to characters possessed now only by herbivorous mammalia, such as horses, cows, deer, &c. From this and other strange characters seen in the Dinosaurs, we learn that they in their day played the part of our modern quadrupeds, whether carnivorous or herbivorous, and showed a remarkable approach to the mammalian type, which of course is a much higher one."[2]

Dr. Mantell had unknowingly been chiefly engaged in building up and restoring what turned out to be the lesser iguanodon, which came ultimately to be known as *Iguanodon mantelli*, in honour of himself, the discoverer.

[1] "Extinct Animals," 1905, p. 239.
[2] "Extinct Monsters," by the Rev. H. N. Hutchinson, B.A., F.G.S., 1893, p. 93.

Dr. Mantell grouped his results in a Memoir communicated to the Royal Society of London. His descriptions and drawings were considered so important that the Society awarded him one of its gold medals.

While Dr. Mantell succeeded in establishing the main features of the iguanodons there still remained a few obscure points. These were satisfactorily cleared up by the researches of Professor Huxley and Mr. Hulke, and

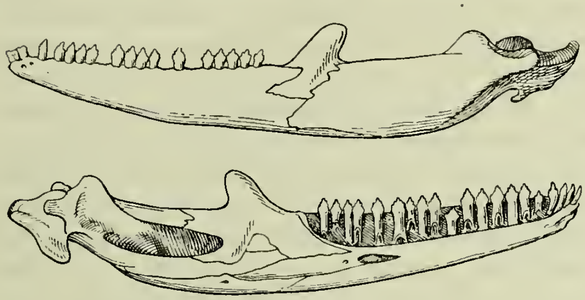


FIG. 548.—Lower jaw of Iguana.

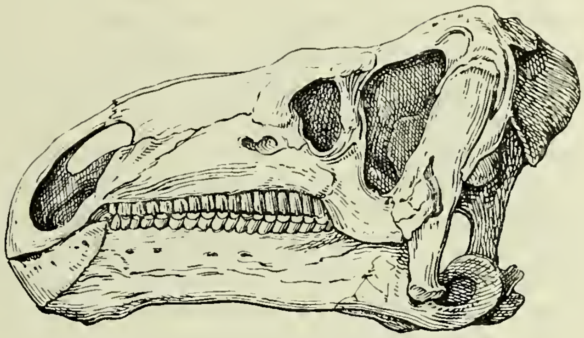


FIG. 549.—Skull of Iguanodon.

by the discovery in Belgium, in 1877, of entire skeletons of the great iguanodon (*Iguanodon bernissartensis*) (Figs. 554 and 555, pp. 1315, 1316). Other workers besides Dr. Mantell were early in the field, notably Dr. Buckland, Professor Owen, Baron Cuvier, and Mr. Conybeare.

The first iguanodon tooth was discovered in 1822 by Mrs. Mantell in the débris of certain strata in Tilgate Forest

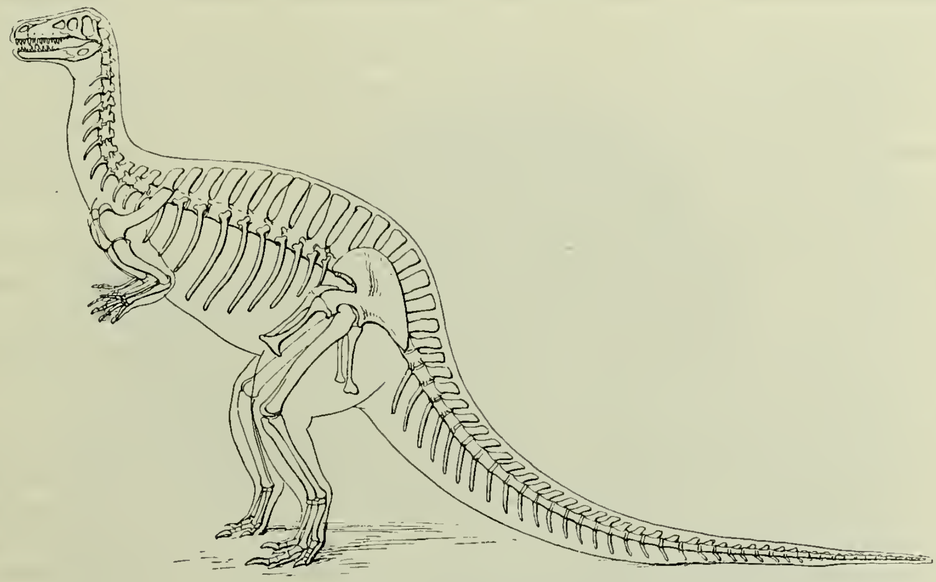


FIG. 550.—Megalosaurus.

belonging to the Cretaceous period. Subsequently Dr. and Mrs. Mantell made an important collection of the teeth and bones of the iguanodon and Dinosaurs generally.

They were greatly assisted by discoveries made long afterwards by Mr. Bensted. This gentleman in 1834 found in the Kentish Rag quarries of the lower Greensand at Maidstone a valuable connected series of iguanodon bones, which he duly presented to Dr. Mantell.

As early as 1824, Dr. Buckland described to the Geological Society of London certain remains of a strange and formidable reptile taken from the limestone of Stonefield, near Woodstock, in the vicinity of Oxford. The remains consisted of part of a lower jaw with formidable teeth and fangs, a femur or thigh bone, several vertebræ, and a few ribs and other bones. Dr. Buckland gave the name of Megalosaurus, or great lizard, to the unknown monster, and from the nature of the teeth concluded it was a carnivorous Dinosaur (Fig. 550). Professors Owen and Phillips entertained similar views. Dr. Mantell, as explained, had previously discovered the bones and teeth of the iguanodon and other Dinosaurs in the Wealden strata of Tilgate Forest. The remains of Megalosaurus

were also found in Sherborne in Dorset; in the Lias at Lyme Regis; in the inferior Oolite near Bridport; in the Great Oolite and marble beds at Enslow Bridge; in the Oxford clay at Weymouth; in the Coral Rag at Cowley; and in the Coralline Oolite at Malton, Yorkshire. The fossil remains were widely diffused in England, and have been rendered classic by the researches of Dr. Mantell, Dr. Buckland, Professors Owen and Phillips, and others. The Megalosaurus is now regarded as the typical carnivorous Dinosaur, as the iguanodon is regarded as the typical herbivorous Dinosaur. The bones of the Dinosaurs were, for the most part, hollow, to make them light as well as strong. It is not yet determined whether the Dinosaurs laid eggs or brought forth their young alive. Professor Marsh, of Yale College, U.S.A., favours the latter belief.

In 1836 Dr. Buckland in his Bridgewater Treatise referred to a large limb bone preserved in the Museum at Oxford. This bone was examined by Baron Cuvier, who regarded it as belonging to a whale. It was also examined (1838) by Professor Owen, who at first thought it might belong to the flipper or paddle of a whale, but subsequently came to the conclusion that it was a reptilian bone, probably the bone of an extinct crocodile. Professor Phillips, who succeeded Dr. Buckland at Oxford, pronounced this and similar bones sent to Oxford as Dinosaurian in character. In 1848 Dr. Buckland directed attention to another large limb bone (a femur or thigh-bone). It was 4 feet 3 inches in length. This, Professor Owen referred to Cetcosaurus. Between the years 1868 and 1872 a large portion of the skeleton of a Ceteosaurus was discovered at Kirtlington Station, near Oxford. This find was carefully examined by Professors Owen and Phillips, and yielded important information. In this case the femur or thigh-bone measured 5 feet 4 inches. Other finds of the Ceteosaurus are to be recorded. Thus in the Kimmeridge Clay of Weymouth, a large humerus or arm-bone nearly 5 feet long was found. Vertebræ of this huge beast were obtained from the Wealden strata of Sussex, several counties in England, and the Isle of Wight. Professor Owen, with a knowledge of all the facts, came to the conclusion that the Ceteosaurus must have been from 35 to 36 feet in length. Yet another English Saurian, the Ornithopsis, is to be chronicled. It was found in the Wealden strata in the Isle of Wight, and was carefully examined by such competent observers as Mr. Hulke and Professor Seeley. Their conclusions regarding it were confirmed in a striking manner by the discovery at a later period of Brontosaurus.

The English finds of Dinosaurs, while admittedly very important, have been somewhat overshadowed of late years by the more numerous, larger, and better preserved finds on the flanks of the Rocky Mountains, North America, where entire skeletons of the largest Dinosaurs, such as Atlantosaurus, Diplodocus, and Brontosaurus have been recovered. Professor Marsh, of Yale College, U.S.A., has been the leading spirit in the search for and exhumation of the extinct monsters referred to, and already over 200 specimens have been secured and fittingly housed in Yale College, the Carnegie Institute, Pittsburg, and other American museums.

Professor Marsh has done much to popularise this important subject by a series of most instructive memoirs and papers, which should be in the hands of every one interested in palæontology. Mention should also be made here of other American workers in this and similar fields, such as Leidy, Cope, Scott, and Osborn.

It only remains to refer very briefly, and in a general way, to some of the more outstanding extinct reptiles, the eras in which they flourished, and to indicate where and under what circumstances they were found, their peculiarities, sizes, shapes, &c.

The Theromorphs formed the oldest group. They flourished during the Triassic age, their remains being found in the Triassic sandstones and limestones of South Africa, India, Russia, Scotland, and parts of England. They immediately preceded the extinct order of the Dinosaurs, which belonged more strictly to the Jurassic age.[1] The Theromorphs derived their name from certain portions of their skull, jaws, and teeth resembling similar parts in the Theria or mammals. They are supposed by some to have occupied among vertebrates common ground, where reptiles, mammals, and batrachians branched off. This, of course, is a mere conjecture, intended to support the theory of descent from one or a very few ancestors and centres.

A good example of a Theromorph reptile is the Pariasaurus from Cape Colony, which had a short neck and tail, a round, ponderous body, and measured 8 feet in length. It more resembled a mammal in general appearance than any form of ancient or modern reptile. It was about the size of a well-grown ox, but was low set, having four short, strong, equally developed legs. The Pariasaurus, there can be little doubt, was a herbivor or plant feeder. This seems proved by its comparatively small teeth.

A fine specimen of the Pariasaurus, set up by Professor Seeley, is to be seen in the Natural History Department of the British Museum, London. Quite a large number of these interesting reptiles in a more or less perfect

[1] Professor Marsh, in the *American Journal of Science* for June 1892, describes the skeleton of certain Triassic Dinosaurs which are deposited in the museum of Yale College, U.S.A. If he be correct in his conclusions some Dinosaurs must have made their appearance before the Jurassic age. This view is favoured by the footprints of Dinosaurs found on the sands and mud of the shore between low and high water marks during the Triassic age. The footprints were first referred to birds, but it was pointed out that the foot of the African ostrich (our largest modern bird) measures only 10 inches, whereas some of these footprints measured as much as 20 inches. Professor Hitchcock avers that in the valley of Connecticut the footprints of no less than thirty-two species of bipeds and twelve of quadrupeds have been discovered. They have been observed in some twenty localities, and cover an area of 80 miles or thereby from north to south in the states of Massachusetts and Connecticut.

condition were obtained by Professor Amalitzky of Warsaw from the banks of the river Dwina, near Archangel, Northern Russia. These and other great reptiles were, curiously enough, found embedded in large nodules of rock which during its formation had supplied them with a strong covering or envelope. From one of the nodules, Professor Amalitzky extracted an enormous and truly formidable carnivor, which he designated Inostransevia. It had a skull two feet in length furnished with huge tiger-like teeth, and must have been a terror to every living thing near it. As it was a contemporary of the Pariasaurus there can be little if any doubt that it fed upon that large herbivore and whatever else edible came in its way. The Inostransevia of Russia was the most terrible carnivore known. It exceeded in size and strength the great carnivorous reptiles of the Cape, such as the Cynodraco, Cynognathus, and Lycosaurus, which, like itself, preyed upon the Pariasaurs and other vegetable feeders.

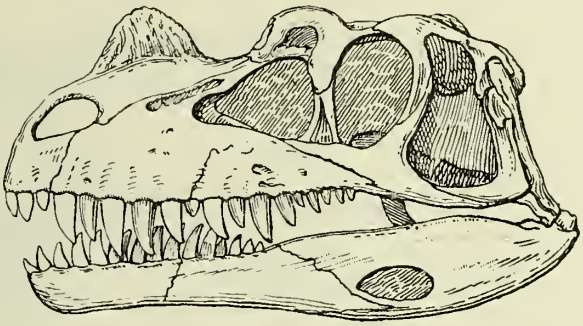


Fig. 551.—Skull of Ceratosaurus.

Professor Marsh in his excavations discovered a peculiar new form of carnivorous Dinosaur to which he gave the name of *Ceratosaurus nasicornis* from the skull displaying a horn (Fig. 551). It was about seventeen feet long, and had a powerful set of re-curved teeth or fangs which somewhat resembled those of the Megalosaur.

It differed from the other carnivorous Dinosaurs in the following respects :—

(*a*) Its body was protected by elongated plates in the skin as in the crocodile.

(*b*) The eyes were shielded by arched bony protuberances in the skull.

(*c*) The brain was relatively larger than in Brontosaurus and its allies, indicating superior intelligence.

Fig. 552.—Dimetrodon.

(*d*) Its fore limbs were small when compared with its hind ones as in Megalosaurus, and some of the digits terminated in powerful claws.

(*e*) The vertebræ were of a peculiar form, and the bones of the pelvis were fused together as in modern birds.

The great carnivorous reptiles were all furnished with immense tiger-like teeth for seizing, holding, and lacerating their victims. The Dicynodon had two powerful tusks, and the skull and teeth of Cynognathus greatly resembled those of a bear.

Professor Amalitzky came upon another Theromorph reptile in one of the numerous nodules in his possession, namely, the Dimetrodon (Fig. 552). It was a crested animal, and was found also in the Permian strata of Texas,

U.S.A. The Dimetrodon presented a formidable and forbidding aspect. It was less remarkable for its size than for its unusual appearance.

The greatest extinct reptiles occurred in the Jurassic age. They were known as Dinosaurs (from the Greek δεινός, terrible; and σαῦρος, a lizard), and belonged to the extinct order of that name.

The Dinosaurs, although usually colossal in size, were not always so. There were some families the members

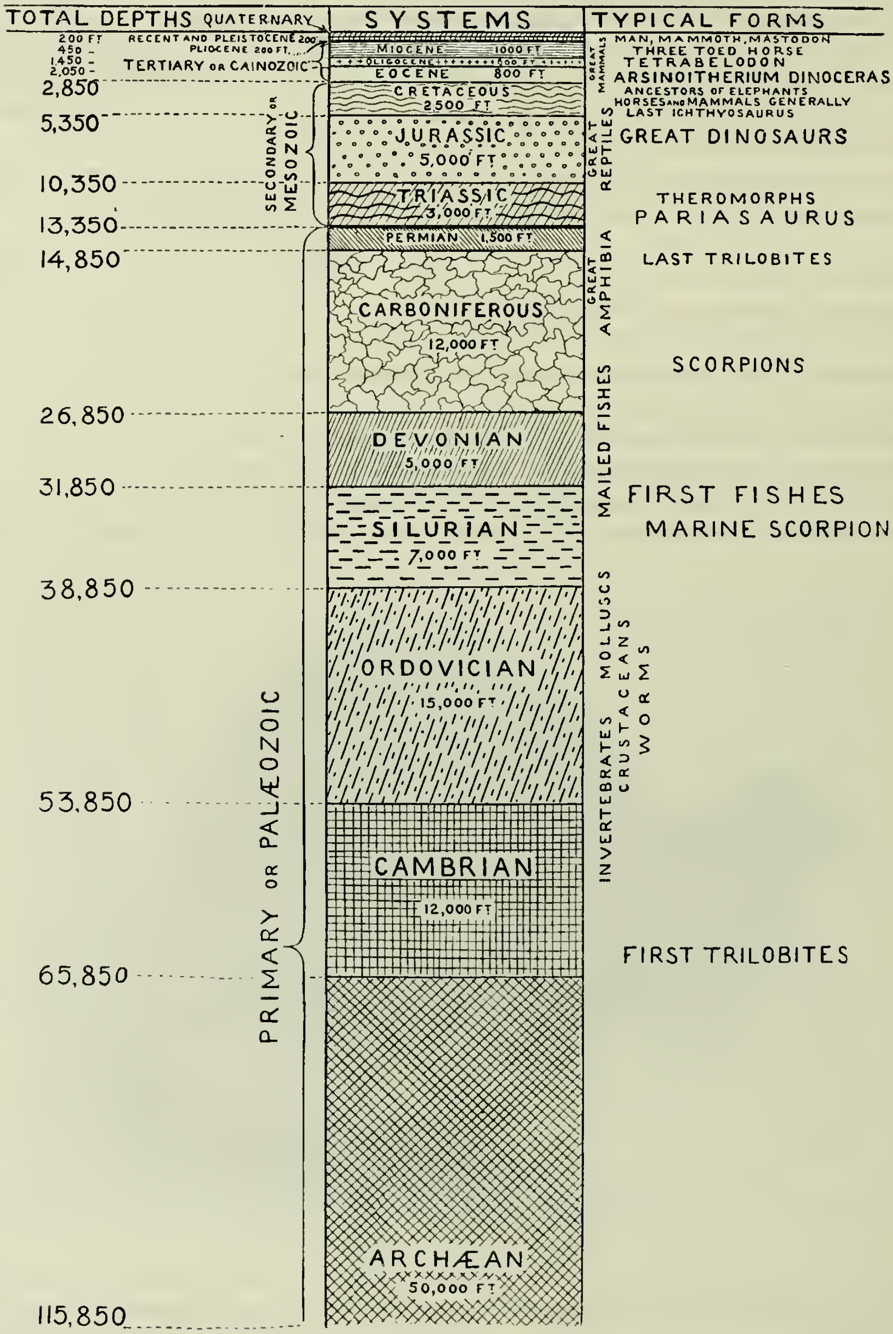


FIG. 553.—A tabular view of the strata of the earth's crust (after Lankester).

of which did not measure more than two feet in length. Diminutive examples of the Dinosaurs were found in the lithographic limestone of Solenhofen, Bavaria. They were slenderly built, and Professor Huxley contended that they greatly resembled birds in their general configuration. His view, however, was not shared by Professor Owen and other acknowledged authorities in comparative anatomy.

One very important point presents itself in this connection.

The existence of the diminutive Dinosaurs proves very conclusively that mere externalities, such as environ-

ment and an unlimited supply of rich, nutritious food, do not of themselves necessarily account for the presence, side by side, of the very large and the very small contemporaneous Dinosaurs. The explanation must be sought in type, in design, and in original endowment.

Of late years, and to the permanent injury of science, it has been the fashion to speak of externalities and

TABLE OF STRATIFIED ROCKS

Periods.		Systems.	Formations.	
	Quaternary.	Rcenet	Terrestrial, Alluvial, Estuarine, and Marine Beds of Historic, Iron, Bronze, and Neolithic Ages	Dominant type, Man
		Pleistocene	Peat, Alluvium, Loess Valley Gravels, Brick-earths, Cave Deposits, Raised Beaches, Palæolithic Age, Boulder Clay, and Gravels	
Cainozoic.	Tertiary.	Pliocene	Norfolk Forest-bed Series Norwich and Red Crags Coralline Crag (Diestian)	Dominant types, Birds and Mammals.
		Miocene	Oeningen Beds, Freshwater, &c.	
		Eocene	Fluvio-marine Series (Oligocene) Bagshot Beds, London Tertiaries (Nummulitic Beds)	
Secondary, or Mesozoic		Cretaceous	Maestricht Beds, Chalk Upper Greensand, Gault Lower Greensand, Wealden (Neocomian)	
		Jurassic	Purbeck Beds, Portland Beds, Kimmeridge Clay (Solenhofen Beds), Coralline Beds, Oxford Clay, Great Oolite Series, Inferior Oolite Series, Lias	Dominant type, Reptilia.
		Triassic	Rhætic Beds, Keuper Muschelkalk, Bunter	
Primary, or Palæozoic		Permian or Dyas	Red Sandstone, Marl, Magnesian Limestone, &c. (Zechstein) Red Sandstone and Conglomerate Rothliegende	Dominant type, Fishes.
		Carboniferous	Coal Measures and Millstone Grit Carboniferous Limestone Series	
		Devonian and Old Red Sandstone	Upper Old Red Sandstone Devonian Lower Old Red Sandstone	
		Silurian	Ludlow Series Wenlock Series Llandovery Series May Hill Series	
		Ordovician	Bala and Caradoc Series Llandeilo Series Llanvirn Series Arenig and Skiddaw Series	
		Cambrian	Tremadoc Slates Lingula Flags Menevian Series Harlech and Longmynd Series	
		Eozoic-Archæan	Pebidian, Arvonian, and Dimetian Huronian and Laurentian	Dominant type, Invertebrata.

environment as the chief, and indeed the only factors, which make animals what they are. Little or no attention is paid to design, to type, and to original endowment. The great Power which is behind and which works in and through animals is ignored: only the scaffolding, so to speak, of creation is recognised—the Master-builder who

plans, arranges, and regulates everything, and who is invisible, being deliberately set aside for what can be seen and felt, and what is, after all, the veriest husk of the great problem of life.

The question of size in the great extinct reptiles, as in modern animals, has much significance when regarded as a fundamental constitutional problem. Biology would benefit largely if anatomists and physiologists, instead of busying themselves with expounding trifling differences in structure and function, concentrated their attention on leading general principles, such as type, constitution, inherent powers, ultimate object to be attained, &c.

Animals are not automata, and they cannot be treated on purely mechanical lines as mere machines. On the contrary, they are living entities which have resources within themselves, or on which they can draw, and which cannot be set aside without inflicting irreparable injury, and wantonly destroying many, if not all, the properties which make them what they are. Nor does the mischief rest here. The important subjects of a First Cause, design, continued supervision, and adaptation teleologically considered, are all prejudiced, if not sacrificed. The existence in geologic time of the colossal and the diminutive Dinosaurs points a moral which the reader will do well to ponder.

The Dinosaurs have been variously grouped. Professor Marsh has divided them into five sub-orders. Others have recommended a threefold division. However classified, they had certain features in common which had better be stated.

1. They were, as a rule, very large.
2. They had, for the most part, long, flexible, powerful necks and tails.
3. They had undersized anterior and comparatively very large and powerful posterior limbs.
4. They had very small heads and brains considering the enormous dimensions of their bodies—the bodies frequently weighing several tons.
5. They had small teeth and masticated their food.
6. They were herbivorous or plant-feeders ; only a few of them being carnivora or flesh-feeders.
7. They frequented marshy, well-watered districts, and led a semi-aquatic existence.
8. They browsed on vegetation abundant and nutritious beyond precedent, which finds no parallel in modern times.

While the great Dinosaurs culminated or attained their zenith in the Jurassic age, it is not to be inferred that this age was exclusively given up to them. On the contrary, it was distinguished by its great crocodiles, tortoises, and batrachians ; also by old-world fishes, insects, and plants—especially ferns.

The several geological ages are indicated by the thickness of their strata and by the remains of plants and animals found in them. The successive geologic periods will be readily understood by a reference to the table of stratified rocks on p. 1312.

In this table it will be seen (*a*) that by far the greatest thickness of strata is found deepest in the bowels of the earth and is the most ancient ; and (*b*) that the thinnest strata occur near the surface of the earth and are the most recent. It will be found also that only the simpler animals are met with in the deeper and older strata, and that the more complex animals are found only in the more superficial and later strata. It will be observed further that the simpler and earlier animals preceded the more complex and later animals in the order of creation. "We get fishes at the top of the Silurian, and we get in the Carboniferous great amphibians ; and the first reptiles in the Permian ; and then we get birds and crocodiles in the Triassic : and the first hairy, warm-blooded quadrupeds in the Jurassic. The highest animals are the latest to appear." [1]

A table of stratified rocks (see p. 1313) is furnished by the Rev. H. N. Hutchinson in his "Extinct Monsters" [2] (Appendix 1), in which he adds a Quaternary or fourth period to the Tertiary or Cainozoic period, and supplies more detail than is given in the table just quoted. Other and similar tables occur in the work.

It is exceedingly difficult to estimate, even approximately, the duration of geologic time from the thickness of the superimposed strata forming the crust of the earth ; a circumstance emphasised by the fact that the strata during the formation of the said crust have, in not a few cases, been broken up and re-deposited again and again.

It will be safe to assert that the time occupied in the formation of the strata, as we now know them, was fabulously great.

It has been estimated that 1000 years of time should be allowed for each foot of stratum (a time all too short in the opinion of many cautious palæontologists), and that, judged by this standard, the recent and Pleiostocene or uppermost layer of the earth's crust, which is only some 200 feet in thickness, would represent a cycle of geologic time equal to 500,000 years. If it takes 500,000 years to deposit strata 200 feet thick, what shall we say of the time required to deposit the strata of the Primary or Palæozoic age, which embraces

[1] "Extinct Animals," by Professor E. Ray Lankester, M.A., LL.D., F.R.S., London, 1905, p. 62. [2] "Extinct Monsters," London, 1893.

the Archæan age, with strata 50,000 feet thick; the Cambrian, with strata 12,000 feet thick; the Ordovician, with strata 15,000 feet thick; the Silurian, with strata 7000 feet thick; the Devonian, with strata 5000 feet thick; and the Carboniferous, with strata 12,000 feet thick? We get into overwhelmingly large figures which we cannot possibly adequately realise. Such figures and calculations fill the mind with astonishment, and throw a reflected light on the immeasurable antiquity of the earth and of the plants and animals which have from time to time inhabited its surface. The seven days allotted to creation in Scripture becomes unintelligible, and will so remain unless a new mode of estimating the length of the days and the nature and amount of the work performed in each day be discovered.

It is not necessary to pursue this subject further at present, unless in so far as it applies to the Jurassic or great reptilian age.

The Jurassic age, like primeval time generally, was measured geologically by the depth or thickness of its strata, which was 5000 feet. It represented, according to our limited ideas, a vast lapse of time, and was sandwiched between an older age—the Triassic with strata 3000 feet thick, and a more recent age, the Cretaceous, with strata 2500 feet thick.

As showing the great duration of the Jurassic age with its huge reptiles and strata of 5000 feet, it is interesting to note that it embraced a period nearly equal to the Cretaceous, Eocene, Oligocene, Miocene, and Pliocene ages taken together; these ages belonging to and constituting the Tertiary or Cainozoic age, in which appeared the great races of huge extinct mammals, such as the Dinoceras, Arsinoitherium, Tetrabelodon, Mastodon, Mammoth, &c. The horse and man also appeared during the Tertiary or Cainozoic age.

Fig. 554.—Iguanodon.

The Tertiary, according to those who do not recognise a Quaternary, is the most recent of all the ages. Going backward in time and deeper into the crust of the earth we come to the Secondary or Mesozoic age, which embraces the Cretaceous, Jurassic, and Triassic ages. The Secondary age is intermediate between the Tertiary or Cainozoic on the one hand, and the Primary or Palæozoic on the other.

Pursuing the same order, we come next to the Primary or Palæozoic age, which is the oldest of all. It includes the Permian, Carboniferous, Devonian, Silurian, Ordovician, Cambrian, and Archæan ages, with aggregate strata of 100,000 feet.

The element of time is an important factor in the appearance and disappearance of animals on the earth's surface, and should never be lost sight of.

The thickness of the strata, as explained, indicates the all but inconceivable periods occupied by the Primary or Palæozoic age—the oldest of the ages—in which appeared the invertebrates, molluscs, crustaceans, worms, mailed fishes, amphibia, &c., as compared with the Secondary or Mesozoic age, noted for its great reptiles, tortoises, batrachians, birds, &c., and the Tertiary or Cainozoic age—the youngest of the ages—characterised by the great races of mammals and man.

As a matter of fact, the most important part of creation, so far as the animals are concerned, was confined to the latest Tertiary or Cainozoic age, which occupied quite an insignificant period in the great work of creation and the world's history. All this becomes very evident when a chart of the sections of the earth's crust is consulted and studied. Such a chart or map shows clearly enough that creation is a progressive work, which requires time for its accomplishment. It does not consist of one instantaneous and stupendous act. As every-

thing is designed and fits into some other thing specially prepared to receive it, and the action of everything, living and dead, is limited, controlled, and co-ordinated, it follows that, however suddenly the creative acts succeed each other, a certain amount of time is necessarily taken up in their performance.

As the Jurassic age leads up to the Cretaceous and other ages which bring us to the present day, so the great extinct reptiles (Dinosaurs, &c.) bring us to the great extinct mammals, of which man is the highest representative. The gradation, advance, and types for which I contend appear in succession at shorter or longer intervals. The types also appear and disappear at intervals. Missing links and vestiges, strictly speaking, do not find a place in creation as we know it.

The great extinct reptiles are, obviously, a race by themselves. They form an independent order of beings. They cannot be traced to pre-existing forms, neither have they left any recognisable descendants. We behold in them peculiarities seen in, but not confined to, the mammals. They cannot be classed with reptiles, amphibians, or batrachians proper, and it requires more than a stretch of the imagination to classify them, even indirectly, with birds.

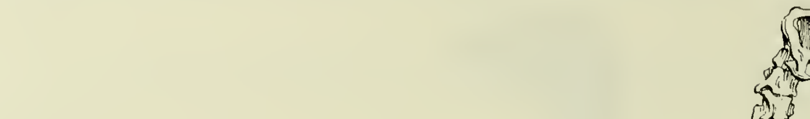


Fig. 555.—Skeleton of Iguanodon.

The extinct reptiles were numerous, and, in many cases, of colossal size. One of the first discovered in a perfect state, and on the whole the best known, is the Iguanodon (Figs. 554 and 555), of which the *Iguanodon bernissartensis* furnishes the classical example. This was discovered in 1877. I have had frequent opportunities of studying perfect examples of this celebrated reptile at the Royal Natural History Museum, Brussels, which contains a large and unique collection of it (twenty-nine specimens) taken from the coal-fields of Bernissart, Belgium, at a depth of 1046 feet from the surface, and 975 feet below sea level.[1] One specimen measured 32 feet 6 inches in length, and, when in an erect position, 16 feet 3 inches in height. It had a head somewhat resembling in general outline that of the horse, a medium-sized neck, a large, tapering, thick tail, two short, dwarfed anterior extremities, each terminating in five toes, and two long, powerful extremities, each terminating in four toes —only three of which touched the ground when the animal was walking, as indicated by its footprints left in alluvial and soft ground.

Some of the oldest Iguanodons were found at a depth of 1157 feet.

As already explained, attention was first drawn (1822) to the existence of a great race of extinct reptiles in England, and the remains of the monsters were carefully described and figured by Drs. Mantell and Buckland, Professors Owen, Phillips, Huxley, Hulke, Seeley, and others. The materials of the early workers, although amply proving the existence of the monsters, were scant, and no complete skeletons were secured. It was otherwise in Belgium and some other countries, especially America. On the slopes of the Rocky Mountains (North America) for several hundred miles large accumulations of the reptiles were met with ; so much so that Professors Marsh, Cope, and their co-workers obtained several hundred specimens, some of them in a wonderfully good state of preservation—indeed perfect, as fossils go.

The fossils were found in the Jurassic sandstone and rock of Wyoming, Colorado, and other parts of the great

[1] Associated with the Iguanodons were other reptiles, batrachians, fishes, insects, and plants. The following is a list of the finds: Two skeletons of a crocodile (*Goniopholis simus*, Owen); a new crocodile (*Bernissartia fagesi*); two new tortoises (*Chitracephalus dumoni* and *Peltochelys duchastellii*); a new batrachian (*Hylaobatrachus croyi*); numerous specimens of fishes belonging mainly to the Lepidotus and Amia groups; the fragment of a wing of a neuropterous insect (*Hylaoneura lignei*), and quite a large number of plants, mostly ferns. No molluscs occur in the list, and it is supposed that their shells were dissolved by the fluids by which at one period or other they were surrounded.

American continent and comprised specimens of most of the largest Dinosaurs ; amongst others, the *Atlantosaurus excelsus*, the *Diplodocus carnegii*, *Brontosaurus excelsus*, *Ceteosaurus*, *Megalosaurus*, *Ceratosaurus nasickenis*, *Stegosaurus*, and others.

In addition to the great Dinosaurs here referred to, Professor Marsh and those associated with him found quite a large number of crocodiles, tortoises, and fishes ; also several small marsupials and one pterodactyl or flying reptile.

The Atlantosaurus has been assigned the first place as regards size. According to Professor Marsh it must have been over 80 feet long and 30 feet high. An idea of the huge proportions of this reptile will be obtained when it is stated that its femur or thigh bone measured 6 feet 2 inches in length, and that it had a body a third larger than the body of the largest modern elephant (Fig. 556).

The longest of the extinct reptiles known at present is the *Diplodocus carnegii*, a fine specimen of which has been recently set up in the Carnegie Institute, Pittsburg, Pennsylvania, U.S.A., and a replica of which has been presented by Mr. Carnegie to the Natural History Department of the British Museum, London. This truly gigantic reptile measured 84 feet 6 inches in length, and 13 feet 6 inches in height at the shoulder ; with outstretched, erect neck it must have attained an altitude of 40 or more feet. It was discovered, along with the other great reptiles, at Wyoming, North America, in the Jurassic deposits for which that district is celebrated. The Diplodocus had a remarkably small head, a very long, powerful neck, and a massive, thick, tapering tail. Its fore and hind legs were fairly equally developed, and all four were employed in walking. Its body greatly exceeded in size that of the largest elephants. Judged by its small teeth it was herbivorous and fed upon plants. Judged by its small brain and its feeble spinal cord it was a peaceful, sluggish, and in no sense an aggressive, animal. It preferred marshy localities and rampant luxuriant foliage where it could feed and conceal itself. Its life was probably largely aquatic—an existence for which its long neck and tail admirably adapted it.

Fig. 556.—Thigh bone of Atlantosaurus.

The Brontosaurus may be cited as a good example of a great extinct reptile (Fig. 557). It bore a certain resemblance to the Atlantosaurus, and weighed several tons. Like the Diplodocus it had a small head and brain ; a large, long, powerful neck ; a thick, tapering, massive tail ; strong, equally developed fore and hind limbs. The bones of the limbs were solid ; the other parts of the skeleton being porous, spongy, and light. It had small teeth, was a herbivore, and fed on juicy marsh plants. It apparently came to its death by being mired in the soft ground it frequented. Judged by its small head, brain, and slender spinal cord, it was a sluggish and, on the whole, a rather stupid animal. What it lacked in intelligence it probably made up in cunning. There are good grounds for believing that it walked on all fours. This is rendered probable by the comparative equality in the size of the fore and hind limbs. The Iguanodon, where the fore limbs were greatly dwarfed and the hind ones very greatly developed, was supposed to have walked on its hind limbs as a biped. The Iguanodon could only have so walked for short distances, unless the tail were brought into requisition.

The Brontosaurus was so colossal that a man could walk erect in front of the fore legs under the neck ; the hind legs being of correspondingly great dimensions. It was some 60 feet in length, and had a heavy ponderous body. It was found in the Colorado district of North America in the Atlantosaurus beds, and seems to have been semi-aquatic in its habits, and to have lived an inoffensive life, taking refuge in concealment or in the water when pursued. Its long neck enabled it to feed on juicy aquatic plants and roots, and its great tail would be very effective as a swimming organ.

The Ceteosaurus, nearly allied to the Brontosaurus and Diplodocus, had a body larger than the biggest elephant, with a height of 14 feet.

The Triceratops had two large and one small horn on its skull—the skull being over 6 feet in length (Fig. 558).

Its limbs exceeded in size those of the largest rhinoceros. The reptile was 25 feet in length, and had a long, powerful tail.

The huge Stegosaurus had hind legs which were nearly twice the length of a well-grown man, and its body was proportionately large. It was provided with five digits to each foot, and was in some respects one of the most remarkable of the Dinosaurs. It was found at Colorado, on the eastern slope of the Rocky Mountains, in strata of the Jurassic age, by Professor A. Lakes and Mr. Beckwith, engineer in the United States Navy. Its remains were discovered in the locality which furnished the gigantic Atlantosaurus. Professor Marsh described this extraordinary reptile in 1877 in the *American Journal of Science.* In 1879 Professor Marsh announced the discovery of Stegosaurus remains from several localities. Portions of over twenty specimens have now been recovered. The monster was 25 feet long, and presented several striking peculiarities.

1. It was a most uncouth, formidable-looking animal (Fig. 559), and derived its name from large bony plates

Fig. 557.—Brontosaurus.

as well as large and small spines on its skin. Some of the plates were from 2 to 3 feet in diameter, and two of the spines were each 2 feet long.

2. The head was relatively very small, and the spinal canal at the sacrum expanded into a long, wide cavity which some think contained a second or supplementary brain for regulating the movements of the great hind limbs and long, powerful tail.

3. The fore and hind limbs (Fig. 560) were well developed, the fore limbs being much shorter than the hind ones. The bones of the limbs were solid, indicating an aquatic or semi-aquatic existence.

4. The reptile, judging from the skull, had large eyes protected by bony protuberances : it had also fairly developed smelling organs, if one may form an estimate from the nasal passages.

5. The teeth in the jaws were arranged in a single row, which when worn out were replaced by others which occupied a position beneath them.

The great extinct reptiles formed the largest terrestrial and semi-aquatic animals which have ever lived. When moving about in the landscape they must have been veritable mountains of flesh. All modern animals, even the elephants, are puny by comparison.

While the extinct reptiles were colossal in size they were also. in many cases, grotesque in appearance. They

were characterised, as a rule, by greatly elongated necks, small anterior and large posterior extremities, and long, powerful, tapering tails; the limbs and tails resembling, but in a greatly exaggerated form, those of modern kangaroos. The huge tails and greatly developed hind limbs formed a basis of support for the ponderous bodies and long necks of the reptiles. They enabled the animals to swim, walk, or sit in a semi-erect position when browsing on tall grasses, shrubs, and trees. They also enabled them to make vigorous forward leaps on occasion;

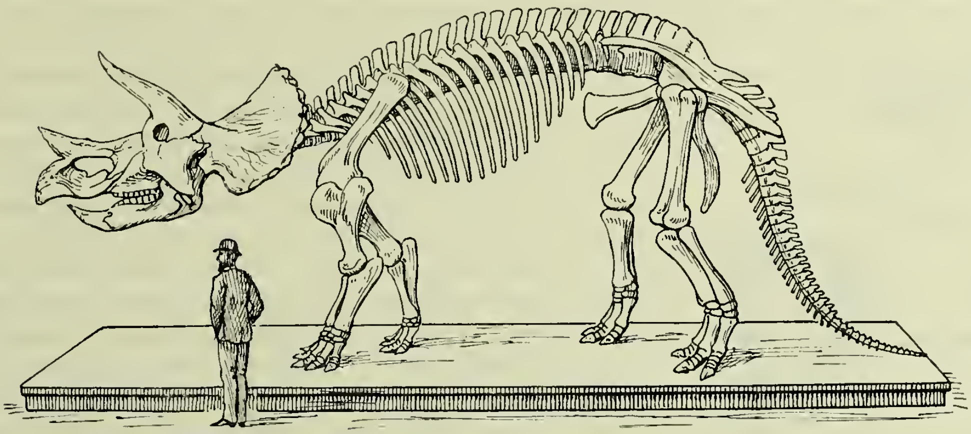


FIG. 558.—*Triceratops prorsus* (after Marsh).

a power of immense importance to the carnivorous reptiles, which sprang upon their prey. The small fore legs, when the animals were standing on all fours, had the effect of bringing the head near the ground, thus enabling the herbivorous reptiles to crop the shorter plants and the carnivorous reptiles to devour their victims. The greatly developed tail had yet another function. It was largely instrumental in preventing the heavy bodies of the reptiles sinking to dangerous depths in the mud of the sluggish streams, lagoons, marshes, and soft grounds which they frequented,

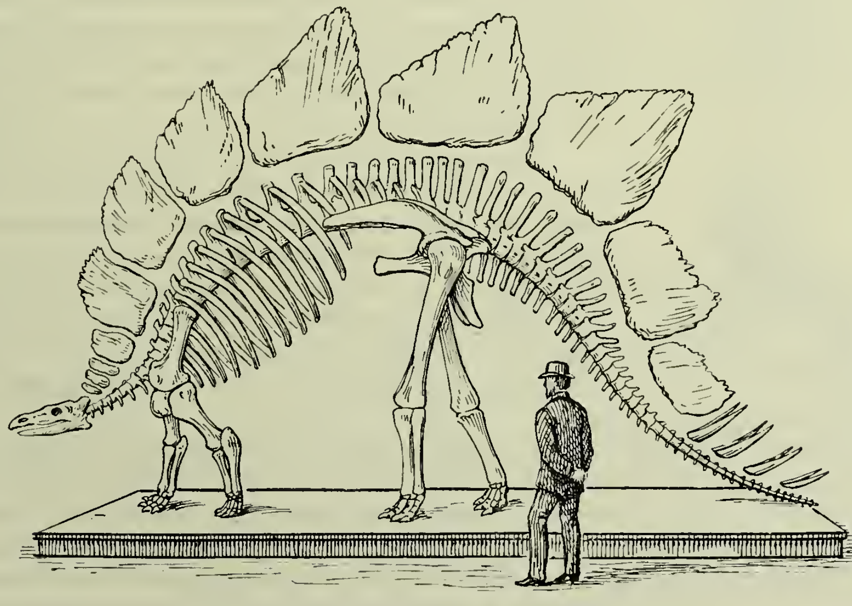


FIG. 559.—*Stegosaurus ungulatus* (after Marsh).

in the same way that the steps of a ladder placed horizontally enable one to walk over thin and dangerous ice. The tail when the animals were walking was trailed along the ground, and in some instances lifted clear of it. In the latter case the reptiles assumed a semi-erect position, and progressed after the manner of bipeds for short distances.

The fossil marsupials, it may be stated in passing, were twice the size of the modern ones. They were conspicuous examples of the excess of growth characteristic of the old-world fauna.

One of the most remarkable peculiarities of certain of the great extinct reptiles (and it has been already adverted to) was the comparatively very small size of the head and brain as compared with the body. This in

the case of the Ceteosaurus, Diplodocus, Brontosaurus, and Stegosaurus was altogether phenomenal, and indicated a low intellectual standard. Indeed the brain in some of the cases mentioned was so small that it could be drawn through the spinal canal. The brain was comparatively little developed as compared with the spinal cord, which was greatly developed, especially in the regions which supply the neck, tail, and limbs with nerves. It was so tiny that its bulk, as ascertained by casts of the interior of the cranium, was only one-tenth that of modern reptiles.

In early geologic times (Triassic and Jurassic) the conditions of life were peculiar. There was, as already explained, a superabundant supply of rich, nutritious vegetation everywhere, and the majority of the extinct reptiles were herbivorous. They fed exclusively on plants. The carnivorous or flesh-feeding reptiles were comparatively few but very formidable. The extinct reptiles, which fed on the rampant vegetation everywhere prevailing, were, at the time referred to, rarely hunted or disturbed. There was, so to speak, no need for large brains in the herbivorous reptiles. Everything was provided for them, and their security within their grazing grounds was, in great measure, secured. They were rather in the position of domestic animals artificially fed and protected, than wild animals accustomed occasionally to short rations and the frequent raids of carnivorous beasts which sought to devour them. That the brain, like every other part of the body, is developed by exercise and work is proved by this, that the brains of wild animals are larger than those of domestic ones, and the brains of carnivorous animals than those of herbivorous. The hunters must circumvent, by brain power and superior intelligence and strategy, the hunted. To this there is no exception.

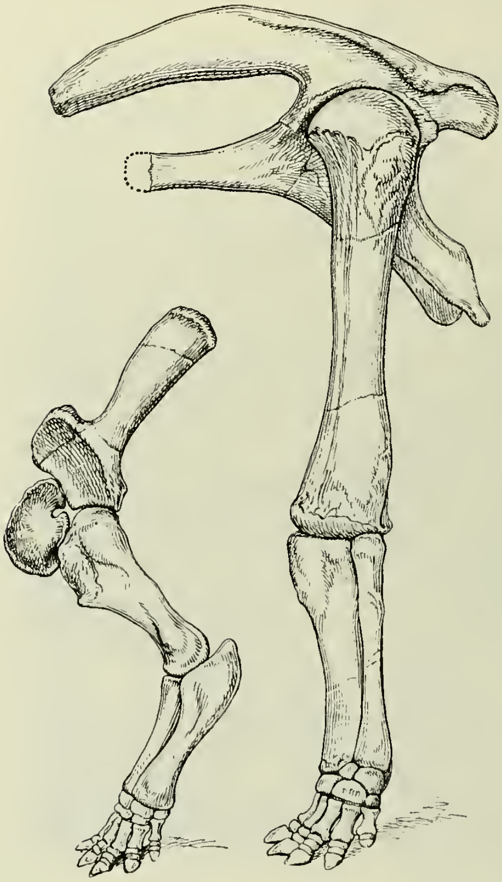


FIG. 560.—Limb bones of Stegosaurus (after Marsh).

The great extinct reptiles were not all small-brained. In some of them the organ attained very considerable dimensions. This was especially the case in the extinct carnivorous or flesh-feeding reptiles, of which are to be mentioned the formidable Dicynodon, with two huge tusks, and the Cynognathus, with a skull and teeth greatly resembling those of a bear. Most formidable and dreaded of the carnivorous reptiles was the terrible Inostransevia, which had enormous tiger-like teeth. The skull of this monster was about two feet in length. It lived at the same time as the herbivorous Pariasaurus, and no doubt fed upon it and other herb-eating reptiles and animals of the period.

The gigantic horned Dinosaur, *Triceratops prorsus*, was characterised by a huge head and a brain smaller than any vertebrate of the same size. The head seen sideways somewhat resembled that of the rhinoceros. The resemblance was emphasised by the formidable horns on the head. It had four well developed and not disproportionate fore and hind limbs, walked on all four legs, and, at first sight, might have been mistaken for a large mammal. The Dinosaurs, as already explained, are regarded by many as representing the herbivorous and carnivorous quadrupeds of modern times.

It is a striking fact, that in the great extinct reptiles death, as a working part of the scheme of life in vertebrates, was in full operation. A certain proportion of the reptiles lived upon their fellows and whatever else came in their way. The carnivorous reptiles with large teeth fed upon the herbivorous reptiles and other animals with small teeth, and the latter fed upon plants. Death in the plant or in the animal was a necessity of life. Death as a concomitant of life was introduced into the world long anterior to the advent of man upon the earth. It is important to mention this here, as many hold that physical death in man was the result of transgression and sin, which, regarding man as an animal, was not the case.

Remarkable as the great extinct reptiles were in many ways, they were especially so as regards their small heads, brains, and teeth. As, however, certain of the extinct reptiles were carnivora or flesh-eaters, and fed upon their fellows and herbivora generally, special provisions had to be made in their case. Larger brains and larger and differently shaped teeth became a necessity. These facts furnish a strong argument for prescience, pre-arrangement, and design. Examples of herbivorous, carnivorous, and other teeth are given at Figs. 561, 562, and 563. The chisel-shaped incisors or front teeth of the plant-feeders could not do the work of the flesh-feeders, which required long, pointed, curved fangs wherewith to seize, hold, and lacerate their prey. Neither could the compara-

tively flat-topped molars of the herbivora take the place of the jagged, pointed molars of the carnivora. The uses to which the two kinds of teeth were dedicated were wholly different, and that difference was not accidental but fundamental.

The teeth of the herbivorous and carnivorous reptiles were original structures. They had to masticate food which differed in many important particulars, and in order to a perfect division of the two kinds of food employed a special chewing apparatus had to be provided in either case. In man the teeth were still further differentiated, he being an omnivore and designed to live upon all kinds of food.

The special chewing apparatuses in question were supplied at the outset. They were not the result of an after-thought, or of accident, or even of modification and adaptation extending over long periods. The herbivorous and carnivorous reptiles depended for the mastication of their food on their peculiar form of teeth from the time they attained the adult condition, and any failure in the characteristic dentition of each would sooner or later have resulted in starvation. The two kinds of teeth, therefore, were as important to the life of the two kinds of animals as were the brains, hearts, lungs, eyes, legs, or other parts of their bodies. It is quite evident that the herbivorous and carnivorous teeth were fundamental typical productions, in no sense dependent on externalities, or environment, or inherent irritability, or so-called adaptability. They were simply original parts of the original animals, and were necessary to their continued existence.

If the two kinds of teeth failed, the two kinds of animals ceased to exist. This was the case in the olden time, and a similar law prevails in the present day. If the teeth of an aged animal become diseased, decay, or drop out, an imperfect mastication and assimilation result, and the animal dies off more quickly than it would have done if its teeth had remained healthy, intact, and *in situ*. The employment in modern times of artificial teeth by man is visibly protracting his span of life.

If animals had to wait for their teeth until they were developed, modified, and adapted from some neutral living material they would starve before the modifications and adaptations could possibly take place.

Nature has taken great pains with the teeth. She has provided, in advance, so-called milk-teeth, for young individuals. These do duty when the food is partly fluid and partly solid. They are ephemeral, and at a given time disappear and make room for the permanent teeth, which generally last during life. Various contrivances are also introduced for keeping the teeth sharp, these being composed of substances varying in density. In mastication some parts are more worn than others. In some animals even the so-called permanent teeth, when worn out, are supplemented by fresh ones. The teeth not only distinguish the herbivora from the carnivora, they also assist in distinguishing animals as a whole.

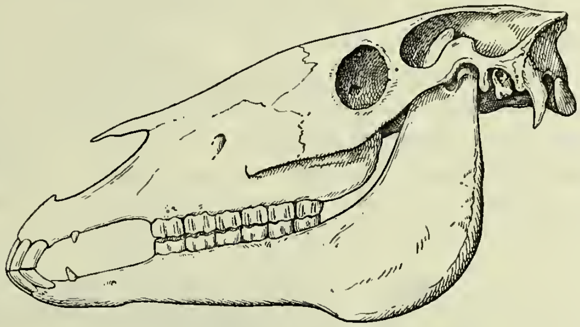


Fig. 561.—Skull of horse, showing incisors and grinding, herbivorous teeth.

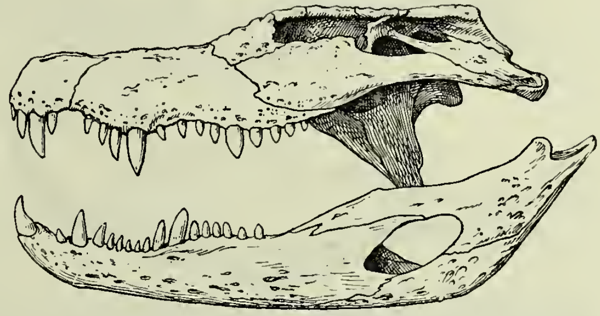


Fig. 562.—Skull of crocodile, displaying lacerating, carnivorous teeth.

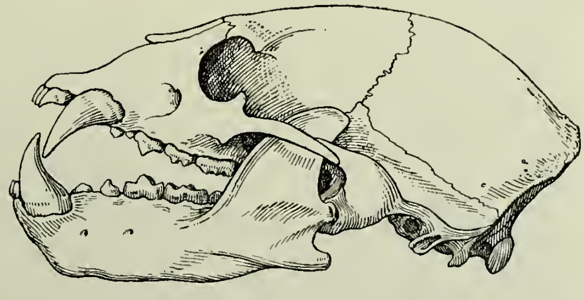


Fig. 563.—Skull of bear with strongly recurved, carnivorous teeth for seizing, holding, and rending.

Man who, as indicated, is a mixed feeder—that is, an animal which lives habitually on a combined diet of plants and animals—possesses, as was to be expected, teeth exhibiting the peculiarities of the herbivora and the carnivora respectively (Fig. 564).

As proving the fundamental character of the teeth, it is only necessary to state that the milk or first set of teeth in man, and in the majority of animals, are planted and partly developed *in utero* long before they are required for the purposes of mastication. There is no question here of externalities, environment, irritability, or adaptation.

As proving the typical nature of teeth it is only necessary to remind the reader that the young of certain whales are provided with teeth which they never use, and which disappear soon after birth.

The foregoing satisfactorily disposes of all arguments which seek to prove that the teeth and the several parts of animals which discharge particular functions are not original endowments, but modifications and adaptations of structures produced by chance influences outside the animals themselves. Those who hold such views seek to create special structures by the aid of environment and other means by what are virtually dead surroundings, and endeavour in a vague and inconclusive way to substitute for a First Cause and design the exploded doctrine of spontaneous generation, with its accidental, hypothetical, non-existent products. In other words, they do their best to convert designed, living animals (every part of which performs a particular function) into dead automata which have no initiative, and where mere mechanical arrangements are called upon to usurp the prerogatives and activities of life.

The differentiation of the teeth in the herbivorous and carnivorous extinct reptiles is already a very old story, but the lesson taught by the differentiation is as important to-day as it was before man made his appearance on the earth. There is, as a matter of fact, no improvement in the herbivorous and carnivorous teeth of the present day over those of the dim and remote past. Notwithstanding the enormous lapse of time between then and now, Nature has not altered her plan even in the slightest degree. What prescience, what permanence, what an endurance of type, and what a wealth of design all this implies! Had the herbivorous and carnivorous teeth been mere modifications and adaptations of some neutral accidental substance with no particular function, the time which has elapsed since the extinct animals lived should have produced something totally different from what actually obtains at the present day. This argument is not met by the hypothetical assertion that, when a modified or adapted structure has reached a stage when it satisfies the requirements of a particular case, the modifying and adapting influences cease to operate. If modification and adaptation are due to the accumulation of innumerable trifling differences occasioned by minute accidental changes extending over long periods, it is the veriest temporising to assume that the accumulations and changes can be stopped at any given time or under any circumstances whatsoever.

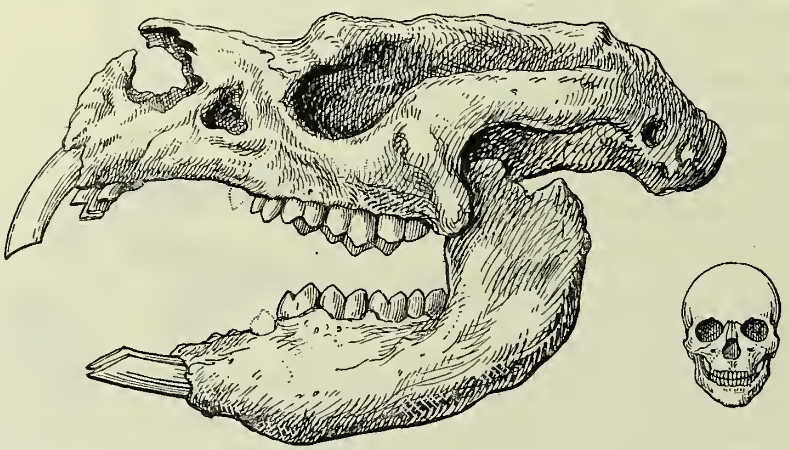


FIG. 564.—Shows the skull of the Diprotodon, one of the extinct kangaroo tribe, remarkable for its extraordinary size. To the right of the figure is the skull of a man, showing how puny it is by comparison. The latter reveals the mixed teeth of the omnivore.

Of course a preliminary question might be raised as to the exact nature of teeth. Some there are who regard teeth as mere unimportant integumentary appendages, such as hairs, nails, horns, and hoofs. The teeth, in such cases, are looked upon as duplications of the mucous and submucous and other tissues of the gums. This view is favoured by the growth of teeth outside the mouth, as in the walls of the uterus, the interiors of cysts, the surfaces of tumours, &c.

Teeth when so regarded form of necessity an integral part of the integumentary system in a designed and specially differentiated system, every part of which has its uses; this is especially true of the sense organs, all of which are skin products.

§ 454. Gigantic Extinct Mammals.

The gigantic extinct mammals come next to be considered, and I cannot do better than quote, in this connection, some interesting observations by Mr. Hutchinson.[1]

"With the advent of the Cainozoic or Tertiary era, we enter upon the 'Age of Mammals,' when great quadrupeds came upon the scene. The place of the reptile was now taken by the mammal. In the long previous era this higher type of life was not altogether wanting, but, as far as the geological record is yet known, it appears only to have been represented by a few primitive little creatures, probably marsupials, whose jaw-bones have been discovered in the New Red Sandstone and the Stonesfield Oolite.

"Geology tells of a great gap between the highest rocks of the Cretaceous period and the lowest group of the succeeding Eocene period. This gap, or break, testifies to a very long interval of time, during which important

[1] "Extinct Monsters," by the Rev. H. N. Hutchinson, B.A. F.G.S., London, 1893, p. 148.

geographical and other changes took place; and consequently we find in the Eocene rocks (at the base of the Cainozoic series) a very different fauna and flora from that which is preserved in the Chalk formation.

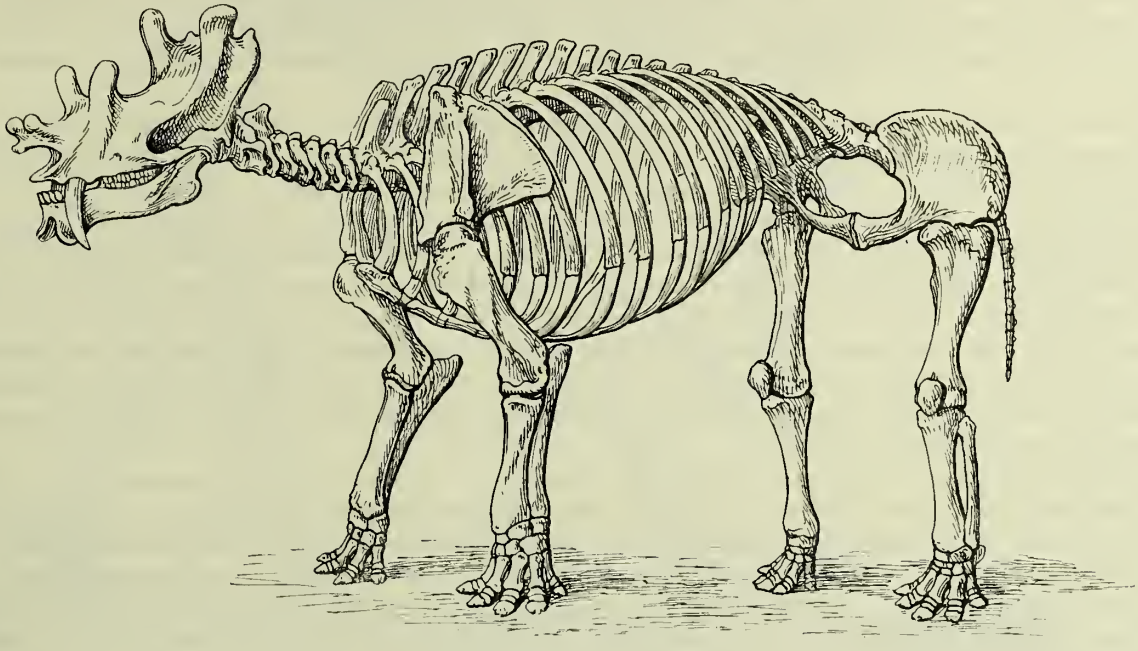


Fig. 565.—*Tinoceras ingens.*

"The researches of Cuvier among the fossils collected from Eocene rocks in the neighbourhood of Paris, especially the Gypseous series of Montmartre, revealed the existence of a very extensive fauna, especially of new types of mammals; and his restoration of the Palæotherium, a tapir-like animal, and other forms, created a vast amount

Fig. 566.—*Brontops robustus.*

of interest, and greatly stimulated the study of extinct animals. As we have already remarked, the science of palæontology may be said to have been founded by Cuvier."

The largest of these mammals were found in the far west of America. In the Eocene period there was a large tropical lake in the Wyoming territory, and around this lake, amidst luxuriant vegetation, lived an extraordinary group of animals called by Professor Marsh Dinocerata, which name implies that they were terrible horned monsters.

I append a figure of one of them (*Tinoceras ingens*, Fig. 565). This great beast had a body 12 feet in length, without the tail, and was calculated when alive to have weighed two tons and three-quarters. On studying this huge creature one is struck with its resemblance to the rhinoceros and elephant.

Another group of great extinct quadrupeds was found east of the Rocky Mountains, and belonged to the Miocene period. One of the best known of these was the Brontops (*Brontops robustus*), which is depicted at Fig. 566.

The Brontops was a heavy, ponderous animal. It was 12 feet long without the tail, and stood 8 feet high. It had short legs, the front limbs having four toes and the hind ones three, as in the tapir. Some are of opinion that it was provided with an ample flexible nose, which formed a rudimentary trunk. Its skull was shallow and very large, and had, on its upper surface, two knobs or prominences which were probably armed with two small horns.

One of the best known and most interesting of the gigantic extinct mammals was the mammoth, a drawing of the skeleton of which is given at Fig. 567.

The mammoth must have occupied a very wide area. As a matter of fact, its remains occur in different regions of half the globe. These remains were so numerous as to form the basis of the science of palæontology.

It was especially abundant in the northern hemisphere, particularly in the frozen regions of Siberia, where a nearly perfect specimen was found. In this, the muscles and soft parts of the body, and even such delicate parts as the eye, were preserved intact. This animal finds a fitting resting-place in the Museum of St. Petersburg Academy.

The tusks of the mammoth were at one time so numerous that they formed an important article of commerce; mammoth ivory was well known almost everywhere.

The remains of the mammoth found in England were mixed up with the bones of the rhinoceros and hippopotamus, and also with those of horses, oxen, and deer. In Ireland the bones of the mammoth were also found.

A mammoth found on the banks of the river Indigirka in Siberia must have been mired in the soft river and other mud, as it was discovered in a standing position.

This animal inhabited great plains or flats covered with small plants and fir trees, on the spikes and cones of which it fed, as shown by the contents of its stomach.

Some regard the mammoth as the root stock of the elephant. It, however, differed from the elephant in the following respects: it was much larger, had a rough head, a low and narrow brain case, a very large mouth and trunk, and unusually powerful teeth.

It was especially remarkable in having a mane and skin covered with flakes of hair.

I give a restoration of this formidable animal (Fig. 568), especially of its exterior.

THE ORIGIN AND CAREER OF MAN

There are two great theories on these important and all-absorbing subjects; the one :—

(*a*) That man has descended from the lower animals by, what is practically, infinite modifications in infinite time by a process of evolution, and has worked his way up; the other

(*b*) That man was created by his Maker, the Great First Cause, a complete being, physically, mentally, and morally, and that his present condition is to be attributed to temptation, a fall, and retrogression.

If the authority and teaching of the Old Testament and the possession by man of an extraordinary nervous system and brain be set aside, the preponderance of evidence, many are inclined to believe, is in favour of a lowly origin—that is, a savage or semi-savage origin. I am not of this way of thinking. There is, it appears to me, no proof that man is directly descended from the ape, and indirectly from the mollusc or the monad. The unchanged condition of physical man for the last nine, or more, thousand years is wholly opposed to such a conclusion.

The period in question is sufficiently long to admit of retrogression and degradation to savagery, and even for regeneration and a return to civilisation by the protracted route afforded by the stone, copper, and bronze ages. The first state of man, there is reason to believe, was one of simplicity and virtue, in which an exalted moral nature played a prominent part, as contra distinguished from mere knowledge and the vice which not unfre-

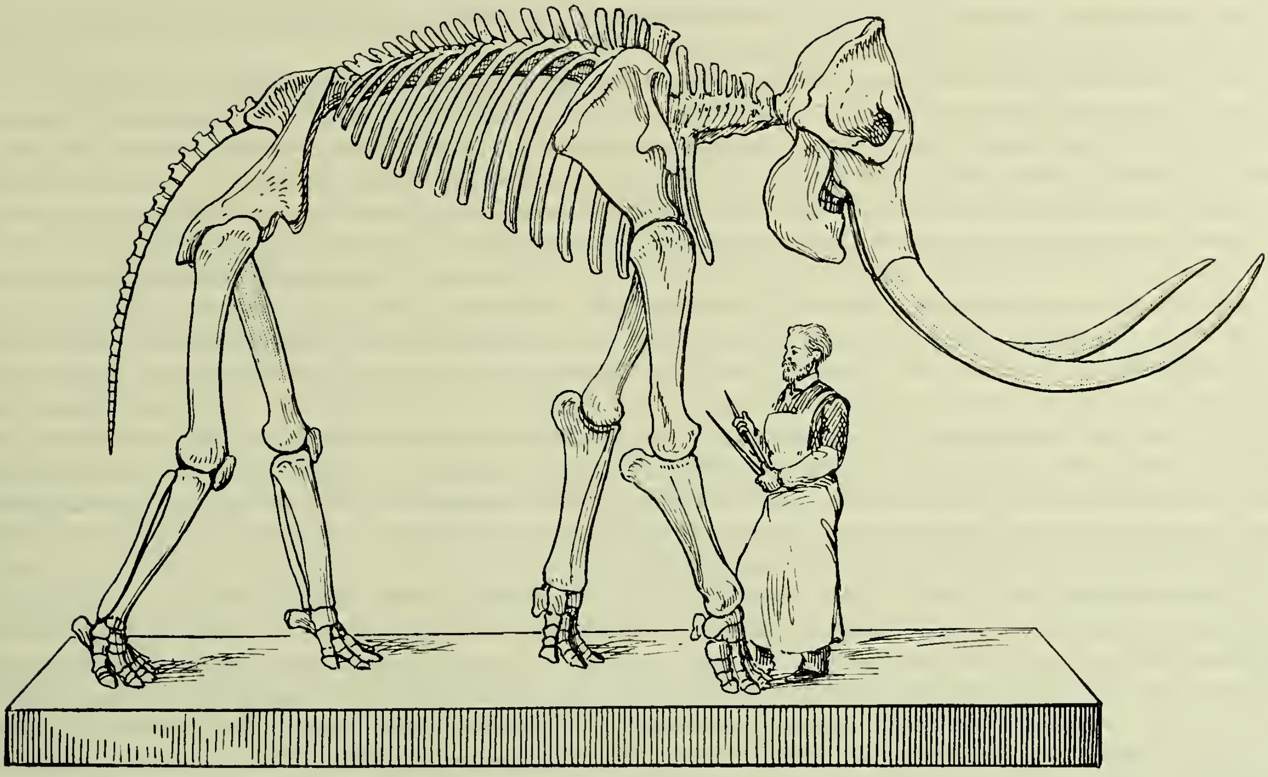


FIG. 567.—Skeleton of mammoth (*Elephas primigenius*).

FIG. 568.—Mammoth (*Elephas primigenius*). It shows the matted flakes of hair which covered the body, and which gave to the creature a wild, ferocious appearance. (Restored by C. Berjeau and the Author.)

quently accompanies knowledge. The Fall, as the outcome of disobedience, destroyed the cordial relations between man and his Maker. He became an alien and an outcast.

His fall and degradation, however, did not preclude his return or partial return to the high platform he once occupied. He was a free agent, and it was open to him to retrace his steps. As he had strayed from the path of virtue and right, and taken to evil ways, it was still in his power to reform. The reforming process furnishes the history of savage peoples in all countries in their attempts at civilisation during the ages. The retrogression and regeneration of man have everywhere followed essentially the same lines; hence in all savage lands the so-called aborigines pass through successive stages of civilisation, popularly known as the stone, copper, and bronze eras.

As man in his original state did not live in dwellings, and had no need for weapons, tools, and implements of any kind, he left no physical traces for the archæologist. It is otherwise with degenerate man—the outcast who had to live by the sweat of his brow, and who was obliged to devise bone, stone, copper, bronze, and other weapons for the exigencies of the chase, and to fashion tools and implements for cultivating the soil, and to live in caves or build huts, all which are more or less in evidence in several countries at the present day. The finds of bone, flint, copper, and bronze weapons, tools, and implements in cave and other dwellings do not prove that man was originally savage. They prove at most that savagery under certain circumstances is a phase of human existence (how brought about is an open question), and that where it prevails or has prevailed the weapons, tools, and implements above mentioned make their appearance. The conditions of life were altogether different in the two cases, so that the same kind of reasoning does not, strictly speaking, apply.

It is a remarkable fact that, so far as is known, the world has never been without civilisation. Long prior to the historic period traces of civilisation are discovered. In the earliest times, as at the present day, civilised and barbarous peoples occupied different parts of the earth's surface. The civilised and the uncivilised, the good and the evil, co-existed. It could not be otherwise. The great laws of retrogression and progression have since the Fall had free play. It is in the nature of things. Even in the most highly civilised communities there are black sheep which persistently take the wrong road. The same is true of families and of races. Races may break away from civilisation and return to it. When they do so, their departure and return are marked by the same characteristics—they pass through practically the same phases in the downward and upward gradients. The finding by archæologists of a graduated series of bone, stone, flint, copper, bronze, and other implements and weapons, of cave dwellings, rude huts, pottery, &c., does not prove that man was originally savage and descended from a monad, an oyster, or a monkey. It only shows that savagery is one of the conditions of modern man.

The savage state, as indicated, can be quite explained by retrogression, and it must be borne in mind that plants and animals, as a whole, ever and anon retrogress. Moreover, the history of the world shows that even the highest civilisation culminates in retrogression. All the great empires and dynasties have, as history informs us, gone to pieces. There is progress up to a point, a zenith is reached, and then retrogression and decay set in. The retrogression is, in many cases, more rapid than the progression, so that savagery in man is by no means an exceptional case. Retrogression is the back swing of the pendulum of progression.

In the early days the conditions of life were easy. The dome of heaven supplied a covering and a home, and the fruits of the earth food. After the dispersion of the races the elements had to be faced, and inhospitable climes occupied and subdued. Stern necessity, the mother of invention, put every one on his mettle, and a race for knowledge, which is the equivalent of power, became the order of the day. Tools, implements, and weapons of all kinds were fashioned, huts built, fire raised, agriculture inaugurated, and flocks and herds reared. As the requirements of all had much in common, so the modes of satisfying them differed little; hence the wonderful sameness of the "finds" in countries widely separated from each other. In Egypt, Africa, France, Germany, Belgium, Great Britain, America, and elsewhere the flint knives, scrapers, arrow and spear-heads, axes, &c., vary little. The same is true of the copper and bronze instruments and early pottery. A like demand resulted in a like supply. The most serious argument that can perhaps be brought against this view is man's dentition. According to comparative anatomists, man's teeth proclaim him a mixed feeder—that is, an animal requiring a mixture of animal and vegetable pabulum. It is true he does not possess the powerful, finely contrived incisors of the ox and horse, or the long, curved, lacerating canines of the lion and tiger; but it may very well be contended that his teeth admirably adapt him for a fruit-feeder. He has no difficulty in dealing with the juicy fruits and the major portion of seeds and nuts; nor must it be forgotten that from the very first he was possessed of very perfect and powerful hands and feet, which were the natural auxiliaries of his teeth. If by sin death came into the world, the Fall, which must have been foreseen and provided for, destined man to be a mixed feeder from the beginning.

It must be added that if death became the punishment of disobedience in man, it could not be so in the case of the animals. As a matter of fact, death has from the first formed part of the great scheme of life, and, as a consequence, the teeth of animals have enabled some to live exclusively on herbs (herbivora): others exclusively

on flesh (carnivora): others partly on herbs and partly on flesh (omnivora). Man is properly classed as an omnivore.

While man is a composite animal as regards his several parts, he is not composite in the sense that he is made from, and represents, all the other animals. The brain of man in volume, complexity, and quality transcends that of every other living form, and establishes an impassable gulf between him and the apes, and everything below the apes. The extraordinary brain of man, while not in excess of his requirements, as the ruler of the whole earth, places him in a category by himself, and marks him out as a being who has received, and is receiving, special treatment at the hands of his Maker, and who maintains, and has always maintained, a more or less direct relation to the Great First Cause who made and upholds the universe.

The special plea here set up for man as a separate and independent creation, originally endowed with prerogatives of a high order, while it separates him more or less widely from the animals, does not deprive him of his animal characteristics. He remains one of the animal kingdom, and shares the realm of animality with every living form beneath him.

That intellectual man is capable of improvement, up to a point, as the result of experience and education, goes without saying. As a matter of fact, he, in common with the whole animal kingdom, has the germs of advance knowledge-ward in himself. There is, however, a limit to progress in man and animals, and also in plants. This fact favours a belief in certain creations, in types, and the division of plants and animals into orders, families, genera, species, &c. While so saying, it is necessary to bear in mind that the division and classification of plants and animals are, in many cases, arbitrary, and a matter of convenience. Still, everything considered, it is more accurate to say that plants and animals are separated from each other by boundaries (ill defined at times they may be), than to affirm that every plant and animal runs into every other plant and animal by insensible gradations, and that each plant and animal proceeds from some other plant or animal, lower down in the scale. The beginnings of things necessitate origins, or types, centres, and points of departure and return for plants and animals respectively.

While the progress made by savage man through the ages towards civilisation points to a lowly origin, it must not be forgotten that over civilisation leads to effeminacy and degeneracy, and the history of the world, so far, shows that up to a certain point there is progression, and, after that, retrogression.

The history of Egypt, and of the Greek and Roman and other empires, sufficiently attests the accuracy of this statement. It remains to be seen whether the civilisation of the twentieth and succeeding centuries is to be something different. If not, it becomes a question whether the civilised condition of man is not his normal condition. In both plants and animals there are many examples of progress within limits followed by retrogression. In other words, there is a forward and a backward oscillation of the pendulum of life at longer or shorter intervals; the real point of departure and return being the normal, typical state between the two extremes. Stability in the vegetable and animal kingdoms seems to demand such a state of things, and, it appears to me, there is a law which regulates it. If law there be in the matter, it would account for the infinite varieties of plants and animals as contra-distinguished from the types; the varieties departing from and returning to the types at shorter or longer intervals according to circumstances. This would result in oscillation, fluctuation, and modification on either side of a given line or centre, without obliterating the line or centre itself; would allow for adaptation to varying conditions without destroying fundamental forms and altering original constitutions.

That man possesses in himself the elements of progress, and that he can move forwards, backwards, or remain stationary, is sufficiently attested by the fact that he is found all over the globe, and accommodates himself to the most varied conditions of climate and physical surroundings. The burning heat of the tropics and the freezing cold of the far north have not stopped his career, although they have made development and advance difficult, and have, in some instances, checked progress, and even resulted in retrogression and disappearance.

The distribution of the human race on the surface of the earth is a subject of great interest; the majority holding that mankind spread from a single centre and from a single pair of ancestors; the minority believing in a plurality of centres and a plurality of ancestors. The question of distribution is less important than that of origin. It has, however, an obvious bearing on the conditions which are favourable and unfavourable to the development and progress of man on the globe.

Great heat and great cold act as deterrents in evoking the highest powers of the genus *homo*. He succeeds best in a mild climate, where he is not enervated by heat, and where he is not numbed by cold. The conditions which suit him best are those supplied by a temperate zone, where he is free to exercise and exert himself, and where food is furnished in plenty but not in excess. The stimulus of exertion is required to elicit his highest powers.

The conditions which favour progress are a suitable habitat as regards climate and soil, social intercourse, competition, sufficiently large communities for intermarrying outside the family circle, and a country which provides

fish, animals, cereals, succulent vegetables, and fruits of all kinds, and in addition, timber, seas, rivers, lakes, rocks, minerals, and metals. Given these, progress is certain up to a point.

The conditions opposed to progress are unsuitable climate and soil, isolation, absence of social intercourse, small communities and interbreeding, too much or too little food, and the need for too much or too little exertion in the performance of the ordinary duties of life. That environment influences, within limits, the career and progress of man is shown by the fact that extremes of heat and cold, dryness and moisture, &c., retard civilisation. We have proof of this in the negro of Africa, and the Esquimaux of the Arctic regions, who are, even now, in a state of semi-barbarism. Other causes besides environment are, of course, at work, as when civilised man competes with savage man. This is proved by the history of the Red Indians in North America, by that of the Bushmen at the Cape of Good Hope, and by that of the aborigines in Australia and New Zealand. All these countries are now, for the most part, occupied by modern civilised man, and, as a consequence, the original semi-savage inhabitants are slowly but surely disappearing. This shows that environment, although a factor in the condition of man and animals in certain localities, is not the only factor, and that race and breed are, up to a point, superior to it. I ought here to mention that some ethnologists are of opinion that the Americans as a nation will deteriorate, and that, even now, signs of deterioration are manifesting themselves. If so, the deterioration will be due not to environment alone, but partly and largely to the great laws of progress and retrogression.

As emphasising the tendency to retrogression, it may be stated that clever parents who have overtaxed their powers very seldom produce talented, vigorous offspring. Similarly, over-bred and over-trained race-horses are, ever and anon, hopelessly beaten by rank outsiders. The over-trained athlete invariably loses his match, and the over-anxious, over-worked student makes a muddle of his examinations. The aristocracy are frequently a feeble race from intermarrying in a limited circle, and from luxury and over-refinement. The blue blood requires to be occasionally mixed with rustic blood. To have perfect health physically, mentally, and morally, a constant intermixing of people and blood, on a wide scale, is necessary. The robust normal standard or type can only be attained under natural conditions.

The progress witnessed in man, as indicated, is shared by animals and plants, but in neither case is it unlimited. There are, so far as is known at present, natural boundaries which may not be overstepped, and which separate the different kinds of plants and animals from each other. The distinguishing feature in man is his highly developed nervous system and brain, which reveal a marvellous degree of differentiation. Even in these, however, he is not wholly separated from such of the animals as are also supplied with nervous systems and brains. Fundamentally, the nerve substance in man and animals is identical. Man possesses more nerve substance in proportion to his bulk and his weight than other animals ; the nerve substance is also of a better quality, but this is all that can be said. The difference is not one of kind but of degree.

If the theory which assigns the origin of man in a perfect form to the operation of a Creator or Great First Cause be adopted, little remains to be said. The Old and New Testaments give his history in a practically complete form.

If the theory that man is descended from the lower animals by infinitesimal modifications extending over essentially unlimited periods be preferred, then the history of the universe as well as of man must be laid under contribution. I can quite understand man's position as the last link in a great chain of being with certain affinities and points of contact with the lower animals, but I fail to see how these affinities and points of contact necessitate his actual descent from the animals next to him in point of organisation.

The advent of the higher biblical criticism, and the rapid strides made of late years by science, especially physics, astronomy, geology, palæontology, archæology, botany, and zoology, make it imperative to treat the Old and New Testaments as historical in character as well as religious and moral, and to modify dates, and, in some instances, even to question outstanding events. Thus it is now generally admitted that the six days assigned in the book of Genesis to the creation of the world must mean 6000 or more years.

Geology, palæontology, botany, and zoology demand long stretches of time for the production of the crust of the earth, soil, rocks, seas, lakes, rivers, atmosphere, climate, &c., and for the formation of plants and animals as they now exist. Doubts have also been expressed as to the several races of man being descended from a single pair—doubts not readily explained away when it is remembered that in the earliest times (as at present) the continents, islands, and patches of land were separated by great seas, lakes, and rivers, and that no boats or means of transport of any account existed. The single or multiple origin of man, it should be stated, does not seriously affect his position as an independent and separate creation.

The stronghold of the doubters is to be found in the account of Noah's Deluge, which is said to have occurred 2200 B.C., or at the earliest 3000 B.C. The date of the Deluge, remote as it may appear, is quite eclipsed by Egyptian and Chaldean dates. According to the monuments and written testimony of these countries, powerful dynasties, great cities, and a highly refined civilisation existed, for certain, 2000 or more years before the date assigned to the Flood.

The doubters affirm, and truly, that the Deluge apart from a miracle is an impossibility. In this universal flood the entire land, according to the description given in the Old Testament, must have been covered by water, in many cases miles deep, and every living thing drowned except Noah's own family and the animals preserved with him in the ark.[1]

The first difficulty, in this connection, concerns the production of the water which constituted the Deluge. Water has to be manufactured. Whence came it? Water in the universe is more or less a fixed quantity. The clouds are supplied with moisture from the sea and great lakes and rivers by means of evaporation, waterspouts, &c. What water is taken from the seas, lakes, and rivers is ultimately returned to them in the shape of rain, snow, or hail, spread over the surface of the earth, and so water circulates without any material increase or diminution.

The second difficulty concerns the number and nature of the animals to be stowed away in the ark for a comparatively long period (twelve months or thereby); some being large, powerful, and fierce, others being small, feeble, and timid, and therefore, in a sense, at the mercy of the larger, fiercer animals. But in addition to the larger and smaller animals referred to there would be myriads of microscopic animals, which, at the date given, could neither be seen nor collected.

The third and chief difficulty concerns the enormous quantity of food, vegetable and animal, required to feed the multitudinous and strangely assorted host.

It is contended that human ingenuity and human hands, at the date assigned to the Deluge, could not possibly have constructed a vessel large enough and strong enough for the purpose, and that the means for accommodating, feeding, ventilating, and keeping the countless throng clean did not exist. This is largely a matter of common sense. The improbability of the occurrence follows on reflection. That there was a vast flood at the date assigned to the Deluge, and that it worked tremendous havoc upon man and beast, one can readily believe, but the greatest conceivable flood would, at best, be partial, and not wholly, or even very largely, destructive of the human race, and of the living things which were man's companions on the earth.

Noah's Deluge, there is reason to believe, was an echo of a similar deluge described by Hasisadra in a Chaldean epic poem of very great antiquity, which was probably based on an astronomical myth. An account of Hasisadra's deluge occurs on a clay cylinder now deposited in the British Museum. Noah's Deluge may, without outraging Holy Writ, be regarded as allegorical, and as teaching the terrible lesson that those who persist in iniquity will inevitably be overtaken by destruction.

The sacred writings lose none of their priceless value by not being interpreted literally in every case. Metaphor and parable are, in numberless instances, employed to convey precepts, and, by implication, commands. The Bible has its historical and common sense side, as well as its moral, ethical, and spiritual side. As it is written, it appeals to all natures: to the scholar, the theologian, the man of science, the philosopher, the simple, and the subtle-minded—to, in fact, every kind of man, and every phase of humanity, past, present, and to come. Taken as a book, it transcends in interest all other books. Its pages are to be studied, not cursorily or carelessly at intervals, but thoughtfully, reverently, and continuously, with all the knowledge at our command. If there are parts of the sacred volume concerning which there are doubts, they are fortunately few in number. The defects, or blemishes as some will call them, are, when compared with the perfections and beauties revealed, less, infinitely less, than the spots on that most glorious of all orbs—the sun. It has been the practice of certain scientists and laymen (the so-called agnostic school) of late years to ignore a First Cause and design, and to discredit religion. Nothing is gained, and very much is lost, by this line of conduct. On every hand, in the animate and inanimate kingdoms, traces of a First Cause and design are apparent, and religion, in one form or other, is avowed and practised by savage, semi-savage, and civilised people in every clime. It has always been so, and the fact is significant, as showing the dependent and *conditioned* state of man in the Universe. If he turns from himself to a Higher Being, it is an admission that he recognises a power, and by implication law and order, outside of himself, to which he is amenable. It also shows that he sees in the power, the law, and the order, means to ends or adaptation; in other words, design. Nor does the matter rest here; his recognition of a Higher Being, and of law and order, implies homage, responsibility, and, within limits, a moral faculty which carries with it in a more or less concrete form the idea of right and wrong, rewards and punishments, and the belief in a here and a hereafter. The dual nature of man as regards bodily and spiritual attributes, and the hope of the continuance of life after physical death, early asserted themselves. Certain savages devoured the hearts of heroes slain in battle, in the belief that by so doing they would transfer their prowess and valour to themselves. Others were fully convinced that after death their spirits entered and took possession of various animals. The latter belief culminated

[1] Considering the height of the mountain ranges, it is estimated that water from three to six miles deep would have been required to submerge them completely.

in the doctrine known as the "transmigration of souls," or "metempsychosis." The doctrine in question plainly indicated immortality, of a kind, and foreshadowed a resurrection.

The religion of the savage is often little more than a gloomy superstition, a craven fear of some impending evil which he seeks to avert by unholy rites. The fetish or deity is more to be feared than loved. It is otherwise with civilised man. His religion is, or ought to be, cheerful, for he sees in the Creator and Upholder of all things a Being to be implicitly trusted, and Whose love and goodness are unbounded. He perceives also that nothing exists by chance, and that everything is foreknown, and, in this sense, predetermined. The higher the civilisation and intelligence, the nearer man is, or should be, to the Great First Cause. The stupendous affairs of the universe are managed in a way which can only elicit profound admiration and reverence in the properly constituted, normal, thoughtful man. If the finite mind does not always grasp the infinite plan, and wrong is apparently permitted to triumph over right, hate to lord it over love, pain to be substituted for pleasure, disease to take the place of health, the good to be downtrodden, and the wicked to flourish, it does not follow, when everything is taken into account, that the best is not done for humanity in the aggregate. The wider purview of the Creator cannot be adequately grasped, but experience convinces most of us, sooner or later, that "what is, is best."

That religion is a necessity in the case of individuals, races, and nations is abundantly proved by its universality. There is this peculiarity about it, it is spontaneous. It wells up like a spring of pure water, and is, in a sense, irrepressible. Not only is it spontaneous, it is also independent. It manifests itself in individuals, races, and nations apart from direct or indirect intercourse. It also assumes common phases. In savage and semi-savage nations it takes the form of polytheism represented by images or idols, each image or idol indicating a god or spirit presiding over certain places, things, or people. As civilisation advances, the number of gods or spirits, and the images or idols representing them, become fewer in number. A period at length arrives when the images or idols are discarded, and polytheism merges into monotheism. Even in monotheism, however, which represents oneness or one God, the idea of plurality can still be traced; the God of the Christian consisting of Father, Son, and Holy Ghost. The God of the twentieth century is, for Christians, a triune God—that is, a God consisting of three persons, parts, or natures, inseparable and perfectly blended. There are, of course, Unitarians, who hold to one God in one person, that God being absolute and supreme in all things.

The three great monotheistic religions are Judaism, Christianity, and Mahometanism. The Jews were the first to attain to the lofty conception of monotheism, but even they cling to the belief that a Saviour will one day appear on the earth.

As man rises in the scale of being there is a tendency to unification; in other words, to a localisation of all power, honour, and glory in one great, central Being, Who was, and is, and ever shall be; Who made all things, Who upholds all things, and without Whom nothing can exist here or hereafter. The God here spoken of is crystallised in religion at its best. He is the Great First Cause Who manifests Himself by design, and by law and order in the universe as a whole; Who instituted and regulates the movements of the heavenly bodies: Who created the great races of plants and animals, and Who inaugurates and supervises every change which occurs not only in them but in everything in the heaven above, in the earth beneath, and in the waters under the earth.

He is the great I Am, the All in All, the Inscrutable Beginner, Upholder, and Finisher of everything, the Eternal, the Prescient, and the Omnipresent. All conceivable attributes and powers are His, and to know Him it is necessary to search for Him everywhere, in religion, in the animate and inanimate kingdoms, and in the physical, mental, moral, and spiritual universe. It is not possible to separate the Great First Cause from His works, and from man, who forms a chief corner-stone in these works. From the first, there has been a relation between the Deity and man, and that relation still continues, notwithstanding all that agnostics have said and written to the contrary. The convictions and beliefs of millions of intelligent men have a much higher value than the "know nothing" speculations of agnostics, however erudite and distinguished these may be.

With a First Cause or Being possessed of all knowledge and invested with all power, Who sees the end from the beginning, and Who provides for every possible contingency, creation is a comparatively simple matter, whether that consists of one great act confined to a particular period, or embraces a series of smaller acts extending over practically unlimited time. Time as applied to the Eternal has no significance; with Him a thousand years are as a day.

With such a Being there can be no question of capacity to do anything and everything, and as there is no apprenticeship to serve, and no blundering, it follows that the most complex animals are as easily made by the Creator as the most simple. This view clashes with the view of evolution, which takes for granted that such perfection as is attainable can only be secured by continuous efforts and modifications extending over enormous periods; each succeeding plant and animal becoming more complex and more perfect as time advances.

The Creator is, by the theory of evolution, practically placed in the position of an artisan learning His calling

and feeling His way. He is not regarded as the Supreme Master Who can make a man as readily as a monad. The Old Testament assigns Him His proper place, acknowledges Him as the All in All, and credits Him with the creation of man as a complete being. There is nothing extraordinary in all this. If a Creator or First Cause be admitted, He must be regarded as equal to every conceivable contingency, the creation of man included.

That man was the last animal to be created seems proved by the fact that his remains are not found mixed with the remains of plants and animals in the very early rock formations, but only in rocks of later formation, although still exceedingly ancient. There are, moreover, no reliable existing links connecting him with the higher apes. The Neanderthal skull, with strongly marked superciliary ridges and low, retreating forehead, was supposed to furnish such a link, but, as I have already shown, the skulls of human idiots and other degraded forms not unfrequently present similar traits (Fig. 225, p. 783). These aberrants are in no sense man-monkeys. The intellect of the individual to whom the Neanderthal skull belonged was of a low order, but he was not, on this account, in any way related to the apes. There is nothing in history or science absolutely opposed to the belief that man was separately created at an early period of the world's history, and the fact that it is so stated in the Old Testament entitles the subject to an impartial and even favourable consideration. So long as there is no direct proof to the contrary, the question must, in all fairness, be regarded an open one. It certainly cannot be pooh-poohed, and while the narratives of the Old Testament do not carry us as far back by several thousand years as the records of Egypt and Chaldea, they, nevertheless, afford a very instructive and interesting picture of the legends, traditions, manners, customs, modes of thinking, and the power of grasping and dealing with problems of science and philosophy.

The Book of Genesis possesses supreme interest from its giving an account of the Creation, and the origin or beginning of man.

The description given of these great events seems to consist of two different accounts by different authors. The composite nature of the book is rendered more or less clear by the first two chapters (first chapter and the first two verses of second chapter), and by writing the original Hebrew word "Elohim" for "God," and "Yahve" or Jehovah for "Lord God." In the first account man is created last, male and female, with dominion over everything, animate and inanimate. In the second he is created from the dust of the earth, Eve being formed from one of his ribs soon after the creation of the heavens and earth and the vegetable kingdom; the beasts of the field and the fowls of the air being formed from the ground and brought to Adam to be named.

If the time stated in Genesis for the creation (six days) be interpreted as periods of thousands of years, there is much in the account which harmonises with modern science.

§ 455. Antiquity of Man.

The great antiquity of man is to be inferred from the ancient histories of Egypt, Chaldea, China, India, and other old-world centres of early civilisation; and from temples, tombs, monuments, inscriptions, and writings found in these countries. Egypt is, on the whole, the best known, and yields the richest harvest of information.

The early history of Egypt may be indirectly attributed to King Ptolemy Philadelphus, whose reign began 284 B.C., and who founded the great Alexandrian Library. This enlightened monarch, actuated by a keen desire for the acquisition and spread of knowledge, missed no opportunity of collecting everything which could throw light on his own and other countries. "With this view he had the Greek translation, known as the Septuagint, made of the sacred books of the Hebrews, and he commissioned Manetho to compile a history of Egypt from the earliest times, from the most authentic temple records and other sources of information." Manetho was well equipped for his great task, being a priest of Sebennytus, one of the oldest and most celebrated of the Egyptian temples, and a very learned and discreet man. His invaluable history was unfortunately destroyed by the conflagration of the Alexandrian Library, and all that remains are fragments preserved in the writings of Josephus, Eusebius, Julius Africanus, and Syncellus. Eusebius and Africanus give, in a more or less accurate form, Manetho's lists and dates of dynasties and kings, beginning with the first King Menes, and extending to the conquest of Alexander the Great, 332 B.C. No fewer than thirty-one dynasties and 370 kings are enumerated in Manetho's lists, and the successive reigns of these monarchs include a period of about 5500 years, beginning with Menes and ending with the conquest of Alexander.

Menes, the first historic king of Egypt, is taken to have reigned about 5500 B.C., or 7400 years from the present

time. According to recent researches, civilised man dates back 9000 years, and there is reason to believe that as we obtain more knowledge we shall find his antiquity greatly exceeds this.

The following bears on the subject :—

A recent article in the *Scientific American* calls attention to the results of excavations which have been carried on for some years in the neighbourhood of Naga-ed-Der, in Egypt, by Dr. J. C. Reisner. The site of the work is supposed to be that of the first settlement of man in Egypt, some 9000 years ago. The region, now a desert, was then fertile, and had an abundant rainfall. Egypt did not then depend on the Nile for its fertility. A number of prehistoric mummies have been disinterred, preserved in salt, and wrapped in matting of halfa grass. These are specially interesting as indicating the first stages in the art of embalming, which afterwards attained such perfection in Egypt. They seem also to indicate that these primitive people held the belief that the body would be wanted again. A careful examination of these well-preserved skeletons reveals the important fact that the type has not changed in the long interval of 9000 years. They are said to be racially identical with people now living in the country. The contents of the intestines are also preserved, showing the food they ate and the medicine they took when they were sick. The diseases of which they died could also sometimes be diagnosed. Some had perished of kidney disease, others of gall-stones, or diseased bones. It is thus shown that these diseases are not the result of modern civilisation.

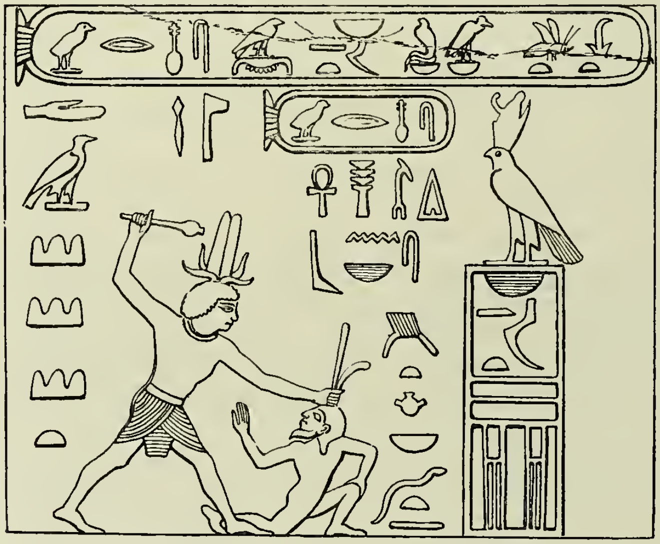


Fig. 569.—Tablet of Snefura at Wady Magerah.

Everything here said goes to prove the vast antiquity of man, but as Egypt was a civilised country, and possessed large cities and an advanced civilisation even during the reign of Menes, many thousands of years must be added to the historic existence of man on the earth. It ought to be stated that authorities differ as to the date at which Menes ascended the throne. Maspero fixes it at 4500 B.C. Mariette, who has compared Manetho's lists with authentic documents from temples, tombs, and papyri, and who is the latest and greatest authority, fixes it at 5004 B.C., which is the date accepted by the majority of modern Egyptologists.

Manetho's lists and dates could only be confirmed by the discovery of contemporary documents in temples and tombs, and by hieroglyphic inscriptions on buildings, monuments, tablets, &c. Fortunately these have been found in considerable numbers.

The most ancient engraved tablet known is that of Snefura at Wady Magerah. It is believed to be 6000 years old, and represents the king conquering an Arabian or Asiatic enemy. This tablet is very remarkable, as revealing great skill in the accurate drawing of natural objects. The tablet displays two human figures, birds of various kinds, a serpent, an insect, hieroglyphics of various kinds, &c. (Fig. 569). The king and his victim are drawn with great spirit, the Eastern features being portrayed with amazing precision; and the birds, especially the birds of prey, are outlined with wonderful truthfulness and dash.

It is impossible to avoid coming to the conclusion that the men, birds, serpents, and insects depicted have not changed from the time the tablet was cut till the present. If to the age of the tablet (6000 years) the time required to produce a civilisation capable of portraying natural objects with such intelligence and skill be added, we are forced to conclude that prehistoric man must date back at least 8000 or 10,000 years, and that without material change.

Mr. S. Laing observes : "That the extremely lifelike portrait-statues, and wooden statuettes, which were never equalled in any subsequent stage of Egyptian art, date back to the fourth dynasty.

"It is singular that this extremely ancient period is the one of which, although the oldest, we know most, for the monuments, the papyri, and especially the tombs in the great cemeteries of Sakkarah and Ghizeh, give us the fullest details of the political and social life of Egypt during the fourth, fifth, and sixth dynasties, with sufficient information as to the three first dynasties to check and confirm the lists of Manetho. We really know the life of Memphis 6000 years ago better than we do that of London under the Saxon kings, or of Paris under the descendants of Clovis." [1]

Other ancient monuments and tablets, many of which I have examined in Egypt, are found where horses,

[1] "Human Origins." London, 1900, p. 24.

oxen, dogs, cats, and other animals are depicted with equal fidelity, and where no trace of change in form can be detected. "The tomb of one of the kings of the eleventh dynasty, Entef I., is remarkable as showing on a funeral pillar the sportsman king surrounded by his four favourite dogs, whose names are given, and which are of different breeds, from a large greyhound to a small turnspit." [1]

A statue of Rahotep's wife, found in 1870 in a tomb near Meydoon, believed to be 5800 years old, represents the features of a highly refined, aristocratic lady, who will compare favourably with the most civilised modern Egyptian (Fig. 570).

All this is in direct antagonism to the theory of evolution and the production of higher from lower forms by continuous modification. If men, horses, oxen, dogs, cats, birds, &c., have not perceptibly changed for 6000 years, it is difficult, and indeed impossible, to believe that evolution is other than a chimera. If ancient monuments furnish direct proofs of immutability and *stability of type* for such protracted periods, it is for modern botanists, zoologists, and physiologists who hold evolutionary views to establish an opposite state of things by actual demonstration. In the presence of such facts it is too much to ask a reading, reflecting, reasoning public to take the theory of evolution on trust, and to be satisfied with the gratuitous assertion that 6000 years are of no account in the production of plants and animals. Such unquestioning credulity would not be asked for in any other department of natural science. So long as facts hold the field, it is vain for fiction in any form to obtain a footing. The fiction is the less to be tolerated when it seeks to obliterate all traces of obvious design and the belief in a First Cause.

Fig. 570.—Statue of Rahotep's wife.

The author of "Human Origins" says, "We know for a certainty, from the concurrent testimony of all history, and from Egyptian monuments, that the different races of men and animals were in existence 5000 years ago as they are at the present day; and that no fresh creations or marked changes of types have taken place during that period." With an authentic record of historic man for 5000 or 6000 years and a pre-existing civilisation, doubtless of long duration, the age of prehistoric man becomes a subject of extreme and ever-increasing interest.

That Egypt could boast an advanced civilisation, at least 6000 years ago, seems certain from this, that about this date it had accomplished priest-doctors, as stated by Dr. Richard Caton in his learned and eloquent "Harveian Oration" for the year 1904. Dr. Caton, in discoursing on "Harvey's Life and Work," expressed himself briefly as follows: "It seemed to amount to this, that Harvey was almost anticipated 6000 years ago by the priest-doctors of Egypt in his momentous discovery of the circulation of the blood. As far back as 4000 B.C. Egypt had works on medicine and anatomy, and one brilliant genius—forgotten nowadays, and omitted from the cyclopædias—I-em-hotep, priest of the sun-god Ra, and physician to King Torsothros, became so eminent that he was revered as a demi-god after death; a temple was built over his tomb; and in his honour hospitals were raised in Memphis and other cities. Here the priest-physicians treated the sick and embalmed the bodies of men and sacred animals. They were probably the first of mankind to acquire a rudimentary knowledge of the movement of the blood. Their papyri contain intelligent references to the heart, the blood-vessels, and the pulse. Of the heart in particular they knew much, and their writings refer to its enlargement, fatty degeneration, displacement, palpitation, and pericardial effusion. One remarkable passage of these old-world inquirers speaks of distension of the heart and shortness of breath as occurring because the blood has stagnated and does not circulate properly. Not Greece, therefore, but Egypt, long before Galen and Hippocrates, was the motherland of rational medicine and anatomy. The views of the Greeks on the circulation of the blood were almost exactly those which the Egyptians had taught many centuries earlier. One remarkable means of treatment for incipient valvular disease of the heart which these long-forgotten Nile doctors taught, was the method recommended at least 4000 years ago—to let the heart have as much rest as possible—a wise injunction, which we may yet practise with advantage. I-em-hotep seems to have been an all-round genius—physician, architect, astronomer, alchemist—so illustrious that after death he was reputed the son of the supreme deity, Ptah—all this and yet nearly lost to fame."

The duration of prehistoric man's existence can only be guessed, but recent discoveries tend more and more to assign him a fabulous antiquity.

As indicating the advance and slow progress of civilisation, it is only necessary to allude to Dr. Schliemann's excavations at Troy and Mycenæ. This celebrated archæologist found no less than seven towns superimposed, the

[1] S. Laing, op. cit., p. 26.

one above the other. The lowest or original town was apparently contemporary with the earliest bronze or later neolithic age ; that immediately above it, with an interval of eleven to twenty feet of débris between, being a fortified city which had been destroyed by fire, which almost exactly corresponds to the descriptions given of Homer's Troy. Troy, as is known, was a walled city, and must for ages have been the seat of a cultivated, powerful people, who were far advanced in commerce, industry, and art.

Amongst other things, Schliemann found no fewer than sixty articles of gold and silver, tastefully and skilfully worked, and displaying not only great refinement, but great wealth and luxury. Among the female ornaments were magnificent specimens of hairpins, bracelets, ear-rings and diadems. To these are to be added vases and cups of terra-cotta, numerous fragments of pottery, &c. The vases are, in many cases, of beautiful and graceful design, and of the shape of animals or human heads ornamented with rosettes, spirals, and other designs peculiar to the pre-Hellenic civilisation of Mycenæ. The third, fourth, fifth, and sixth cities consisted of poor huts built of stone and clay, indicating periods of retrogression. The seventh, or uppermost and latest, formed the Græco-Roman Ilion of classical authors.

The religion of Egypt proclaims the great antiquity of that country. Portions of its Todtenbuch, or Book of the Dead, were written prior to the reign of Menes (5005 B.C.). This remarkable work, considered sacred by the Egyptians, contains the chief prayers and hymns, and an account of the last judgment. Egypt could also boast a religious literature, and works on arithmetic, geometry, mensuration, astronomy, and medicine, all which shows ages of preliminary training, and civilisation of a very early and advanced type.

A knowledge of the exact sciences is, in some respects, a better test of civilisation than religion. The former implies long, laborious study ; the latter may be, and often is, referred to inspiration.

Mr. Samuel Laing states that [1] "in their moral law the Egyptians followed the same precepts as the Decalogue (ascribed to Moses 2500 years later), and enumerated treason, murder, adultery, theft, and the practice of magic as crimes of the deepest dye. . . . In fact the state of civilisation in Egypt 6000 years ago appears to have been higher in all essential respects than it has ever been since, or is now, in any Asiatic and in many European countries."

The building of the greater and lesser Pyramids involved the possession of an enormous amount of precise knowledge in arithmetic, geometry, mathematics, and astronomy.

Several of the most celebrated cities, temples, and sculptures of Egypt can be traced back to a period long anterior to the reign of Menes. The Sphinx may be cited as an example. This, the largest and most extraordinary piece of sculpture in existence, was known to Khufu, the builder of the Great Pyramid. In the paws of the Sphinx Khufu found and restored a small granite temple, decay in which points to an ever-increasing antiquity, concerning which there is no record.

As Mr. Laing puts it : [2] "There is abundant proof that at the dawn of Egyptian history, some 7000 years ago, the arts of architecture, engineering, irrigation, and agriculture had reached a high level, corresponding to that shown by the state of religion, science, and letters. A little later the paintings on the tombs of the Old Empire show that all the industrial arts, such as spinning, weaving, working in wood and metals, rearing cattle, and a thousand others, which are the furniture of an old civilised country, were just as well understood and practised in Egypt 6000 or 7000 years ago as they are at the present day. . . .

"When we turn to the fine arts we find the same evidence. The difficulty is not to trace a golden age up to rude beginnings, but to explain the seeming paradox that the oldest art is the best. A visit to the Museum of Boulak, where Mariette's collection of works of the first six dynasties is deposited, will convince any one that the statues, statuettes, wall-pictures, and other works of art of the Ancient Empire from Memphis, and its cemetery of Sakkarah, are in point of conception and execution superior to those of a later period. None of the later statues equal the *tour de force* by which the majestic portrait statue of Chephren, the builder of the second Great Pyramid, has been chiselled out from a block of diorite, one of the hardest stones known, and hardly assailable by the best modern tools. Nor has portraiture in wood or stone ever surpassed the ease, grace, and lifelike expression of such statues as that known as the Village Sheik, from its resemblance to the functionary who filled that office 6000 years later in the village where the statue was discovered ; or those of the kneeling scribes, one handing in his accounts, the other writing from dictation. And the pictures on the walls of tombs, of houses, gardens, fishing and musical parties, and animals and birds of all kinds, tame and wild, are equally remarkable for their colouring and drawing, and for the vivacity and accuracy with which attitudes and expressions are rendered. In short, Egypt begins where most modern countries seem to be ending, with a very perfect school of realistic art."

In order to have an adequate conception of the greatness and grandeur of Ancient Egypt, it is absolutely

[1] "Human Origins," p. 107.

[2] Op. cit., p. 163.

necessary to undertake a personal visit to the land of the Pharaohs, and to inspect the ancient cities, statues, obelisks, temples, bas-reliefs, inscriptions, tombs, sphinxes, pyramids, the innumerable treasures stored in the great Cairo and other museums, and libraries, &c. So fully was I convinced of this necessity that I undertook a journey in the Nile Valley (as far as the Second Cataract) in the years 1904–5. Untold wonders met my gaze, and of these I took careful and copious notes. On my return to Cairo I spent five hours daily in the museum for several weeks, but found the time all too short for the stupendous task which lay before me. I, however, saw and recorded enough fully to convince me that Egyptian civilisation had attained a much higher standard than is generally realised. I was especially struck with the greatness and grandeur of the temples, the extraordinary size and interest of the tombs, the marvellous accuracy and beauty of the statues and bas-reliefs, the faithfulness and vigour with which men and animals of all kinds are depicted, the number and elegance of the tablets and inscriptions, and the general refinement and luxury everywhere discernible. The Cairo Museum is simply overwhelming in extent and contents —statues, large and small, of men, quadrupeds, birds, reptiles, fishes, insects, &c., in every conceivable material—

Fig. 571.—King Seti I.

Fig. 572.—Rameses II.

wood, clay, the hardest rocks, pottery, &c.; endless sarcophagi with their owners exposed; amongst others, Rameses the Great and his father Seti I. The sarcophagi are numerous, and are in many instances wonderfully ornate, and the same is to be said of the coffins, which, as a rule, display the most exquisite designs and the most extraordinary richness and harmony in colour. The later coffins bear on their lids portraits of the departed. The impression left on my mind was one of endless detail and vastness—a feeling accompanied, on certain occasions, by mental fatigue from sheer inability adequately to realise and partake of the rich repast spread before me. The illuminated papyri of themselves formed a veritable literary feast. Altogether the Cairo Museum is, in many senses, unique.

I append photographs of mummies, statues, and some of the better known works of art.

On the whole the most striking objects in the museum are the mummies, especially those of King Seti I. and his son Rameses II. (the Great). The latter was supposed to be the Pharaoh who harassed the Israelites, and who was held in awe by all his subjects (Figs. 571 and 572).

Rameses II. was by far the most famous monarch ever known in Egypt. He was great in every direction, as a builder of temples, as a warrior, and as the producer of numerous fine works of art.

The following description of his personal appearance was taken by me from his mummy on February 17, 1905. My brief notes on the subject are as follows: Strong features, somewhat Roman nose, mouth large, firm, and a little depressed at the corners, chin projecting and powerful. Dome of head sloped backwards and not very high; it is also narrow. Very firm face—almost cruel. A little brownish hair on either side of head. Good ears. Hands large and long; feet ditto. Tall man. No trace of negro in features. Two teeth seen in right side of mouth.

The account given in my notes of Rameses II. applies with some slight modifications to his father, King Seti I. The head and face of the latter are remarkably fine, better than those of Rameses II., but the same cast of features; more benign. The dome of the head is superior to that of Rameses II., and the face is more refined. There is a less

pronounced Roman nose, a smaller mouth, and a well-rounded, prominent chin. The hands are crossed and touch the shoulders. The hands, as in Rameses II., are large and long. King Seti I. was not so tall as his son, Rameses II.

Rameses II. has left traces of his career all over Egypt. He made many statues of himself, some remarkable for their great size. The celebrated temple of Abû Simbel, which was hewn out of the living rock to a depth of 185 feet, is adorned with four of these huge statues seated on thrones, each measuring 66 feet in height.

The statues are evidently meant to be likenesses of Rameses II., and their enormous proportions can be readily made out by comparing them with those of an adult man.

A photograph of the statues and the temple of Abû Simbel is given at Fig. 573.

A remarkable feature about the early Egyptian statues is that a large percentage of them were composed wholly of wood. Latterly, they were fashioned from all kinds of materials, even the hardest stones. The wooden

Fig. 573.

statues, everything considered, are wonderfully preserved. They are, in some cases, mutilated, but, in many instances, are quite intact.

One of the best examples of the wooden statues is that of the Sheik el Beled, which is acknowledged to be 6000 years old (Fig. 574), known as the Village Sheik. It was found by M. Mariette at Sakkarah, and represents a contemporary of Cheops. It is 1 m. 10 cent. high, and shows the sheik in a standing position, staff in hand. The feet and lower portion of the left leg were wanting, and have been judiciously restored. The statue was originally deposited in the Boulak Museum, but has now been transferred to the Cairo Museum, where I have examined it critically on several occasions.

It represents a perfect man as regards head, features, body, and limbs. It is nearly nude, so that the form and proportions of the several parts of the body can be conveniently studied. The head is large and finely proportioned, and the face intelligent and benign. The eyes are wide apart, the nose well developed, and the mouth and lips firm and expressive. The ear is properly modelled, and displays a highly developed lobe. The trunk is broad, well nourished, and symmetrical; the shoulders and chest being specially powerful. The limbs and hands are remarkably well shaped; the limbs being brawny, and the hands perfect in all their details. There is nothing, in any part of the statue, to indicate even a trace of Simian origin; on the contrary, it reveals a perfect man, who has evidently not changed in the least for 6000 years. This indicates an extraordinary persistence of type in the human race. What is said of this particular statue holds true of other statues, bas-reliefs, and drawings of men and women found in large numbers in Egyptian temples, and on Egyptian monuments, tombs, clay cylinders, papyri, &c.

The beautiful limestone statue of the priest-god, Ra-nepher, a photograph of which I give at Fig. 575, is perfect even in all its details.

I give photographs of some of the beautiful bas-reliefs which were found in the temples and tombs. Among

Fig. 574.

Fig. 575.

these is one of the goddess Isis (Fig. 576), who is represented semi-nude and in a sitting position. This bas-relief is remarkable for its bold drawing and fine finish.

I also give a photograph of a bas-relief with two males and two females. One of the males has a hawk's head, and the females are of extreme physical beauty. The tracery of this bas-relief cannot be surpassed (Fig. 577).

I further give a photograph of a bas-relief with six figures, three of which are represented as having bird's heads. All these figures are depicted with great accuracy and power (Fig. 578).

Finally, in Fig. 579, I give a photograph of a bas-relief with four figures, three of them having crowns and one a crocodile's head ; here, again, the subtlety of Egyptian art is strongly in evidence.

While Egypt contains no monuments of the stone age similar to those found in Swiss lake villages and Danish kitchen-middens, indicating the rude beginnings of civilisation during the neolithic and prehistoric ages, there is, nevertheless, abundant evidence to prove that in the Nile Valley, long before the reign of Menes, the preliminary stages of civilisation had been gone through.

Borings made by Horner in the valley of the Nile yielded products which unmistakably indicate a high antiquity. This archæologist sunk no fewer than ninety-six shafts, in four rows, at eight-mile intervals, across the Nile Valley and at right angles to the river in the vicinity of Memphis.

The shafts were sunk to various depths. Of these some yielded pottery which, at the ascertained rate of deposit of Nile mud (3 inches per century), carries us back at least 11,000 years.

Another shaft at a depth of 24 feet yielded a copper knife, and at 60 feet pottery. A depth of 60 feet, at the normal rate of deposit of Nile sediment, indicates an antiquity of 26,000 years. The copper knife makes it probable that an age of copper preceded that of bronze.

Further evidence of the antiquity of the Egyptians is furnished by the discovery, by Professor Haynes, of flint implements of the neolithic and palæolithic type, and a flint workshop or factory in the neighbourhood of Cairo. Haynes also found large quantities of worked flints of the common neolithic and palæolithic types lying in all directions in the hills near Thebes. These and other finds Mr. Campbell avers "are beyond calculation older than the oldest Egyptian temples and tombs."

Fig. 576.

The foregoing favours the belief that Egyptian civilisation was of extremely slow growth, and that man, as a consequence, has a very much higher antiquity than is usually assigned to him.

Modern research in Egypt and elsewhere has had the effect of exciting doubt as to the accuracy of certain Biblical dates.

Up till the middle of the nineteenth century, and more or less to the present day, it was believed that Adam, the first accredited member of the human race, was created about the year 4004 B.C., or 5911 years from the present time, and that the Deluge occurred 1656 years later than the creation of man, namely, 4255 years from the present day. If the same standard for estimating ancient and modern time be adopted, it appears that a revision and modification of Hebrew chronology will become necessary. According to Mr. S. Laing,[1] "the latest conclusions of modern science show that uninterrupted historical records, confirmed by contemporary monuments, carry history back at least 1000 years before the supposed Creation of Man, and 2500 years before the date of the Deluge, and show then no trace of a commencement, but populous cities, celebrated temples, great engineering works, and a high state of the arts and of civilisation, already existing."

It will be seen that, however great the antiquity of historic man, prehistoric man must be regarded as immeasurably older. The antiquity of prehistoric man will always remain a matter of uncertainty, but recent investigators agree as to the necessity of referring his origin to an incalculably remote period.

The historical records furnished by Egypt in the way of documents, temples, tombs, monuments, tablets, hieroglyphic inscriptions, &c., have been corroborated in the most remarkable manner by recent discoveries in Chaldea.

The Chaldean records carry us back as far or even further than the Egyptian ones. In the earliest Chaldean records there is a good deal that is mythical, but the later records rest on secure foundations. The first Chaldean writer of note was Berosus, a learned priest of Babylon, who flourished about 300 B.C., and who wrote a history of his country in Greek, relying for his information on materials preserved in the temples, and on hoary tradition. His history was unfortunately lost, but from fragments preserved it, curiously enough, began with a cosmogony which bears a certain resemblance to that of Genesis. It then deals with the reigns of ten gods or demi-gods which occupied a period of 4,325,000 years, about the middle of which period a deluge similar to Noah's Deluge is stated

[1] "Human Origins."

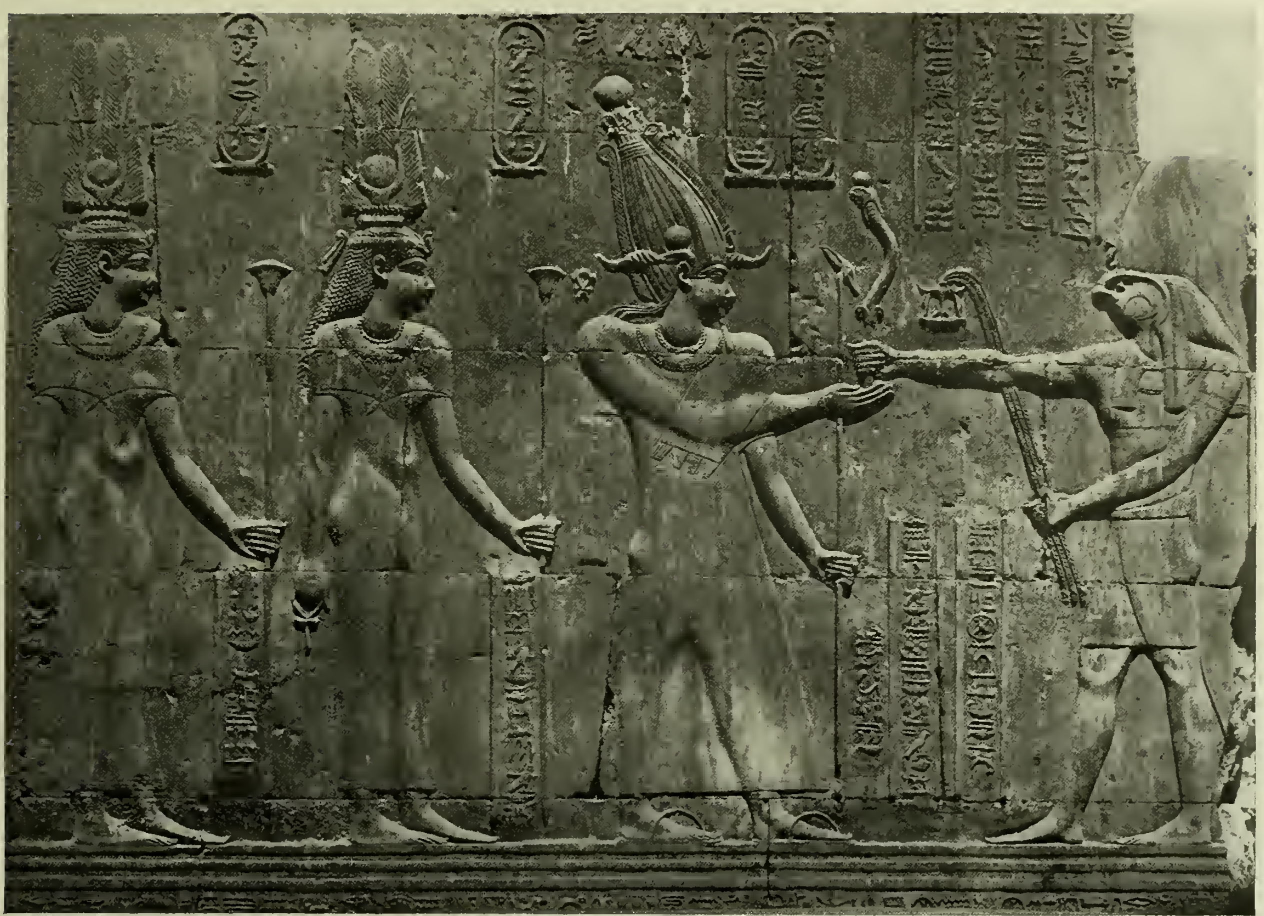


Fig. 577.

to have occurred. He (Berosus) mentions that, prior to the deluge, Chaldea was peopled by a mixed foreign race, who lived without order, like animals.

He then carries back the existence of man to a period anterior to his deluge, which occurred some 216,000 years B.C.

Berosus, strangely enough, also refers to the Tower of Babel and the confusion of languages.

The Chaldees were assigned an antiquity of 3000 years B.C. by their monuments and sculptures, and these, in many instances, were covered with curious, wedge-like, cuneiform inscriptions. Many sculptures bearing those strange and unknown cuneiform characters were found by Botta and Layard in the heaps of rubbish which covered the ruins of Nineveh.

As the Persian kings reigned over a mixed people, their edicts were not unfrequently published in three languages ; namely, old Persian and Zend, Semitic or Aramaic allied to Hebrew, and Turanian. The trilingual inscriptions referred to gave the cue to their meaning, and by the exercise of great ingenuity and patience Grotefend, Rawlinson, Burnouf, Lassen, and Oppert succeeded in deciphering the first two languages. Sir Henry Layard was the means of deciphering the third. This distinguished archæologist discovered under the great mound of Koyunjik near Mosul, on the Tigris, the site of ancient Nineveh, and of the royal palace of Sardanapalus, grandson of Sennacherib, one of the most celebrated of Assyrian monarchs, who flourished 650 B.C. or thereabouts.

The palace contained a royal library rich in Assyrian and Chaldean literature, carefully selected from the best examples of previous libraries and from temples, monuments, &c. The records were in a marvellous state of preservation, from the fact that they were written by means of a style, not on perishable papyri paper or skins, but on cylinders of soft clay, which were subsequently baked in ovens or sun-dried, and, by this means, rendered practically imperishable. Some 10,000 tablets from the royal library of ancient Nineveh have already found their way into the museums of Europe, and give a graphic account of the social life, literature, laws, and religion of a period prior to the Deluge of Noah, and, some are inclined to believe, prior to the date usually attributed to the creation of Adam.

Fig. 578.

The Chaldean records were preserved in yet another way. It was customary in the earliest times, as it is now, to build up in, or under, foundation stones of temples, public edifices, &c., accounts of passing and important events. The hard clay cylinders with their cuneiform inscriptions in this way became invaluable repositories for all kinds of early old-world knowledge. Nabonidus, the last King of Babylon, who flourished 550 B.C., was, fortunately for posterity, a zealous antiquarian, and spent much of his time in unearthing the memorial cylinders placed in the foundations of important ancient temples and buildings by their founders and restorers. He, in his turn, was a restorer and depositor of cylinders, and so the foundation-cylinder literature became continuous.

Nabonidus, in restoring the Sun-temple at Larsam, found in a perfect state of preservation in its chamber under the corner stone the cylinder of King Hummurabi, a well-known historical king, who created Babylon the capital of Chaldea about the year 2000 B.C. King Hummurabi's cylinder explains that the Sun-temple was begun by Ur-ea and completed by his son Dungi, 700 years before his own time. The date of Ur-ea is thus fixed at 2700 B.C., or thereabouts.

Another cylinder furnishes a yet earlier date, namely, that of Sharrakin or Sargon I. of Agade. King Nabonidus, who found the cylinder in repairing the great Sun-temple of Sippar, says "that having dug deep in its foundations for the cylinders of the founder, the Sun-god suffered him to behold the foundation-cylinder of Naram-Sin, son of Sharrakin (or Sargon I.), which for three thousand and two hundred years none of the kings who lived before his time had seen." This shows that Naram-Sin flourished 3750 B.C., or, making allowance for the protracted reign of Sargon I., about 3800 B.C. This discovery carried back the Chaldean chronology 1000 years before the date of Ur-ea, and made it contemporary with the fourth Egyptian dynasty, when the Great Pyramids were built. The Sphinx is known to be considerably older than the Pyramids.

Sargon II., who reigned 2000 B.C., or thereby, founded or enlarged the library at Erech, one of the oldest and best known cities of Lower Chaldea. Erech boasted a priestly college, and was known as the "city of books."

It was a sacred city, and had a famous necropolis with innumerable tombs and graves, which embraced all periods of Chaldean and Assyrian history to the remotest times.

Sargon II., a perfectly authentic character, affirms in his tablet that 350 kings had reigned before him. If this very large number of kings had reigned 2000 B.C., it follows that the chronology of Sargon II. would considerably exceed that of Egypt, and so push further and further back into the remote past the origin, rise, and progress of the human race.

It was at one time supposed that Assyria possessed no statues, but M. de Sarzic not only discovered but brought

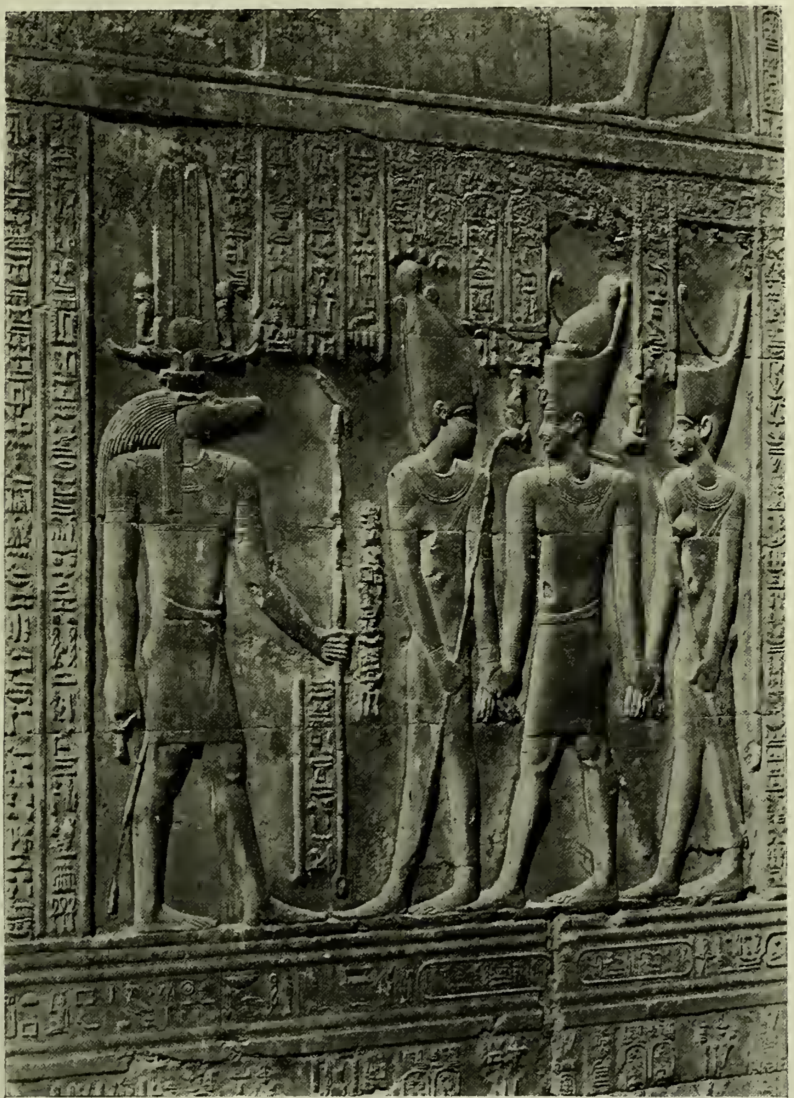


Fig. 579.

home nine large statues of Turanian type hewn out of diorite, a very hard, black basalt. Small statues were also found of men and animals very artistic in design and of elaborate finish. Cylinders were also found, and on all were cuneiform inscriptions giving important and interesting information. One of the statues represented Gud-ea, one of the priest-kings, who, according to the best authorities, lived 4000 or 4500 B.C. The priest-kings lived at the same time as or even preceded the earliest Egyptian kings, and the remarkable thing, in both cases, is, that at that very early period the arts and civilisation in both countries were as advanced as they were 2000 or 3000 years later. "With these facts it will no longer seem surprising that some high authorities assign as early a date as 6000 B.C. for the dawn of Chaldean civilisation, and consider that it may be quite as old or even older than that of Egypt."

When it is remembered that the dates quoted above represent not a beginning of civilisation but a civilisation already ancient, possessing great cities, organised society, magnificent temples, a priesthood, religions inculcating

moral ideas, a system of writing, and books, a knowledge of agriculture, the fine arts, and astronomy (the greatest of the sciences), we are constrained to extend the dates almost indefinitely.

Bunsen is of opinion that it may have taken 10,000 years to bring about this order of things, but even this time seems altogether inadequate.

The eloquent author of "Human Origins" (p. 65) thus summarises this important and deeply interesting subject: "During the whole of this historical period of 6000 or 7000 years there has been no change in the established order of Nature. The earth has revolved round its axis and round the sun, the moon and planets have pursued their courses, the duration of human life has not varied, and there have been no destructions and renovations of life or other traces of miraculous interference. And more than this, we can affirm with absolute certainty that 6000 years have not been enough to alter in any perceptible degree the existing physical types of the different races of men and animals, or the primary linguistic types of their forms of speech. The Negro, the Turanian, the Semite, and the Aryan, all stand out as clearly distinguished in the paintings on Egyptian monuments as they do at the present day; and the agglutinative languages are as distinct from the inflectional, and the Semite from the Aryan forms of inflections, in the old Chaldean cylinders as they are in the nineteenth century."

Before leaving this part of my subject it is of the utmost importance to insist that during the long periods referred to neither man nor animals have changed their type. Those who have written upon evolution have endeavoured to account for the permanence of type in the Nile Valley by saying that the conditions of the Nile Valley have undergone no change for practically an unlimited period.

Professor Huxley asserts that certain animals in the neighbourhood of the Falls of Niagara have not changed at all for 30,000 years.

§ 456. The Human Race in Greek and Roman Times.

To come down to Greek and Roman times, say 400 B.C., or 2300 odd years from the present, one is struck with the remarkable physical and mental beauty and power of the people; especially their perfect symmetry, dignity, and grace.

I illustrate this part of my subject with four plates of photographs of busts, nude and other figures, in bronze, marble, wood, &c., by the great masters of antiquity.

The busts and statues in question, in order to be fully appreciated, must be seen and studied in the original as they occur in the Vatican, in the Capitol, and in public and private collections in Rome, Naples, and elsewhere, where it has been my good fortune and privilege critically to examine them.

PLATE CLXXIX

Plate clxxix. contains photographs of ideal and actual busts in bronze and marble found in Pompeii, Herculaneum, Rome, and other ancient cities. The busts, of which only a few are photographed, are remarkably numerous, and are in a splendid state of preservation. They represent some of the most celebrated characters of antiquity, and are the work of the best Grecian and Roman sculptors. This plate contains a fine portrait of Dante by the famous artist, Raphael; Dante forming a connecting link between ancient and modern man.

The first three figures give spirited delineations of a victorious athlete, the goddess Minerva, and the old-world poet, Homer, more or less ideal in character. Finer heads and faces cannot anywhere be found. They display valour, wisdom, and poetry at their best. More exalted conceptions of physical and mental strength and beauty cannot be conceived.

The remaining figures consist of marble and bronze busts from the life, and include those of Sophocles, the Greek tragedian; Æschines, the celebrated advocate and orator, the rival of Demosthenes; Livia, the wife of the Emperor Augustus; Seneca, the philosopher; and, as indicated, a striking portrait of the immortal Dante by Raphael, verified by a cast of Dante's face after death.

Figs. 9 to 16 also represent ancient Greek and Roman philosophers, warriors, statesmen, and men of letters, among whom may be mentioned Aristotle, the greatest conqueror in the world of thought, who laid the foundation for the sciences of natural philosophy, mechanics, physiology, and natural history; Socrates, the great teacher of morality; Cicero, the statesman and orator; Virgil, the great Roman poet; and Marcus Aurelius Antoninus, the crown and flower of Stoicism.

FIG. 1.—Head of a victorious athlete (Paris—Musée du Louvre). This head, finely domed and proportioned, is an embodiment of physical fitness and power, as indicated by the expanded nostrils and firmly set, compressed lips. It probably takes us back 2000 years. It would be difficult to find a more powerful head and face.

PLATE CLXXIX

PLATE CLXXIX (*continued*)

FIG. 2.—Head of Minerva in marble (Naples—Museo Nazionale). The head of Minerva is the personification of knowledge, wisdom, and resolve. It represents the highest conceivable type of womanly beauty, as indicated by the lofty, finely rounded brow, the dreamy eyes, the delicately chiselled nose, the full, soft lips, and the well-formed chin and lower jaw. In the whole range of statuary no finer head and face can be discovered. This gem of womanly perfection cannot be matched, far less surpassed, by any existing specimen of woman.

FIG. 3.—Marble bust of Homer (Naples—Museo Nazionale). The bust of Homer, the blind Greek poet, furnishes a head and face of remarkable power, earnestness, and sweetness. The wrinkled forehead, the up-turned sightless eyes, the strong, well-formed nose, the careworn cheeks, the partly open, down-turned mouth, prominent chin, and flowing hair and beard, combine to form a semi-sad, singularly attractive, thoughtful face. This bust, which dates from the early Greek period, is more or less ideal, but the countenance bears the impress of reality, and cannot be matched by that of any modern poet.

FIG. 4.—Marble bust of Sophocles (Naples—Museo Nazionale). The marble bust of Sophocles is probably from the life, and one of the numerous bust portraits which have fortunately been preserved to us. Sophocles, the famous Greek tragedian, has a noble head and face—a lofty forehead, thoughtful eyes, a good nose, delicate attenuated cheeks, a firm mouth, and clustered, wavy hair and beard. The expression is singularly benign and pensive. It would be difficult to find a better balanced head or a more refined, thoughtful face. The bust of Sophocles will hold its own with that of any modern intellectual man.

FIG. 5.—Marble bust of Æschines (Naples—Museo Nazionale). The bust of Æschines, advocate, orator, and rival of Demosthenes, is evidently from the life, and displays a remarkably powerful head and face. The dome of the head is at once high, broad, and massive, and the cast of features firm and decided ; the eyes are penetrating, the nose well formed, the mouth firm set, the lower lip, chin, and lower jaw being full. The head is slightly bald, and the ear has a well-marked, dependent lobe. No finer head anatomically can anywhere be found among modern orators.

FIG. 6.—Bronze bust of Livia (Naples—Museo Nazionale). The bronze bust of Livia, the wife of Augustus and the mother of Tiberius, is characterised by a finely domed head with profuse wavy hair. The face is one of reserve power, as indicated by the full eyes, the straight, well-defined, full nose, the closed mouth with ample, finely curved lips, and the rounded, projecting chin. There is a certain saucy hauteur in the face which bespeaks force of character. This bust, found in Herculaneum in 1753, dates back more than 1800 years.

FIG. 7.—Bronze bust of Seneca (Naples—Museo Nazionale). This bronze bust, found at Herculaneum in 1754 and believed to be that of Seneca, displays a very large, compact, powerful head, with a very striking, eager, discriminating face. The dome of the head is high and broad, and the brow furrowed, as becomes a philosopher. The eyes are penetrating, the face wrinkled, the mouth partly open, with thin, firmly set lips. The bust dates back at least 1800 years. It bears a very considerable likeness to Woolner's bust of the Chelsea sage, Thomas Carlyle, one of the most famous of modern thinkers.

FIG. 8.—Drawing of Dante crowned with bay (Rome—Vatican). This drawing by Raphael of the head and face of Dante is an exceedingly fine work, and is substantiated in all its details by the cast taken of Dante's face after death. It shows a finely shaped brow, dreamy, far-off eyes, a prominent aquiline nose, an expressive, firm mouth, and a projecting, rather pointed chin. The face is no ordinary one, and wears a very sad expression. Dante dates back 600 years. He connects the antique and modern heads, and stands boldly out as one of the greatest intellectual forces of all time. He is one of those who appear at long intervals, and are not repeated, which they certainly would be, if man was a mere evolution.

FIG. 9.—This bust of Alexander the Great (Rome—Museo Capitolino) is full of beauty, and is suggestive of conscious strength. The features show very fine proportions, and the head is turned aside as though scorning his vanquished foes and looking for new worlds to conquer.

FIG. 10.—Marble bust of Aristotle (Rome—Museo Capitolino), the pupil of Plato, who was by heredity associated with the science of medicine. The highly arched eyebrows of this figure, with the eyelids slightly closed, show character and concentration of thought. The cheek bones are prominent and the mouth firmly set.

FIG. 11.—As might be expected, the head of Socrates (Rome—Vatican), the greatest of Greek philosophers, is unusually well formed. The forehead is massive and the skull well domed. The eyebrows are prominent and the nostrils broad. The whole face is powerful, and suggestive of intellectual activity.

FIG. 12.—This figure represents Cicero (Rome—Vatican), the man of letters and Rome's greatest orator. The face is a strong one, and full of character. The nose is well bridged, and the whole face is that of a leader of men. The head is supported by a short but not too thick neck, and the whole speaks power.

FIG. 13.—Bust of Julius Cæsar (Rome—Museo Capitolino). This is a very fine type of head, with high cheek-bones and piercing eyes. The ear is well formed, and proportioned to the rest of the head. Alertness is depicted in every feature, and the firmly set mouth shows determination and fortitude.

FIG. 14.—Bust of Virgil (Rome—Museo Capitolino). This masterpiece of sculpture is full of form and grandeur. Thought and expression are indicated by the eyes and graceful mouth. This head represents the ideal of the Greek canon.

FIG. 15.—Bust of Marcus Aurelius Antoninus (Rome—Vatican). In this bust the head and face have short, curly hair, but through this we may see a finely formed skull. The eyes show penetration and quickness, and the poise of the head is good.

FIG. 16.—(Mantua—Museo Civico di Scultura). The subject of this bust is unknown, but the fine head with full face is a specimen of the best Greek sculpture. The face denotes determination and strength, and the thick, muscular neck may be that of a warrior or athlete.

Note.—The conclusion to be drawn from a consideration of the antique heads contained in Plate clxxix. is that 2000 or more years ago the human head and face were as highly developed and as perfect as they are to-day. There is nothing to show

that man is being evolved from a lower to a higher condition, or that he is changing his bodily parts. It may even be doubted whether the intellectual faculties are more exalted The intellectual achievements of the Greeks and Romans are, in some respects, as remarkable as those of modern men. The particular forms of the intellectual activities have changed, but it may be contended that the range and power are little altered. Homer compares more than favourably with any modern poet, and Aristotle with any modern philosopher. The evolutionists evade these and other awkward facts by maintaining that 2000 years is an altogether inadequate time to indicate physical and mental development in man. But, as already stated, we can carry the argument six or more thousand years back in the case of the wooden statuette, "The Village Sheik," deposited in the Cairo Museum, which, according to the chronological table of Mariette, is over 6000 years old. A period of over 6000 years cannot be pooh-poohed in considering the origin, development, and history of man.

PLATE CLXXX

Plate clxxx. contains photographs of four typical nude figures : a male and female (modern), and a male and female (antique). Fig. 1 is an exquisite life study of a girl by Gérome ; Fig. 2 a celebrated Venus in bronze (Venus of Ostia) ; Fig. 3, the renowned Greek boxer, Damoxenus, in marble by Canova ; and Fig. 4, the famous Discobolus or disc-thrower in bronze.

Figs. 2 and 4 are antique gems of the first order, and it will be seen that they compare very favourably with the modern Figs. 1 and 3. The modern figures are identical in every particular with the ancient figures, and the former can boast no advance or improvement on the latter. As a matter of fact, modern men and women do not occupy a higher platform, physically, than ancient men and women.

The figures of this plate are instinct with life and movement, and represent physical humanity at its best. The pose of the several figures is grace itself. The figures have been selected for their anatomical excellences, for purposes of contrast, and because the positions of the limbs are true to nature. The upper and lower limbs, it will be observed, are arranged diagonally in pairs ; the diagonal positions being due to diagonal screwing movements occurring in opposite directions at the shoulders and hips, first pointed out by me in 1867, when describing the movements of walking, swimming, and flying.[1] In that year I explained that when a man walks, his right arm and left leg advance together diagonally in curves to form one step ; his left arm and right leg advancing together diagonally in curves to form a second step. The same holds true of the fore and hind limbs of horses and quadrupeds generally (Plate clxxxi., Fig. 4). In the latter cases the right fore and left hind legs advance together diagonally in curves ; the left fore and right hind legs, in due course, performing similar movements—the two sets of diagonal curved movements alternating. The limbs of bipeds and quadrupeds in the act of walking and running produce what are virtually figure-of-8 tracks in space.

Fig. 1.—Girl playing with balls—nude female figure from the life by Gérome. In this beautiful figure the right shoulder is raised and the right arm screwed forward ; the left arm being depressed, and the left leg screwed forward. Here the diagonal screwing or twisting at the shoulders and hips is seen to perfection. One diagonal half of the body is advanced while the remaining diagonal half occupies a posterior position. The head is slightly averted and looking over the left shoulder. It is impossible to conceive a more graceful or effective pose, as it brings out all the fine curves of every part of the body.

Fig. 2.—Famous antique Venus (Venere di Ostia—Rome, Lateran). In this celebrated antique figure the same points are illustrated as in Fig. 1 ; the only difference being that the right shoulder is depressed and the right arm screwed forward or advanced; the left hip being elevated and the left leg screwed forward or advanced. In both cases, the lower limbs are more or less twisted and plaited.

Fig. 3.—Celebrated marble statue of the Greek pugilist, Damoxenus, by Canova (Rome—Vatican). In Canova's splendidly modelled, powerful nude figure, the diagonal twisting action at the shoulders and hips, and the forward, diagonal, twisting movements of the arms and legs are well portrayed. The figure is a literal personification of determination, strength, and aggressive action. The head is powerfully modelled, and the face is a veritable study of courage and fierceness combined. The muscular masses of the body and limbs are thrown into bold relief, and display wonderful vigour of movement. The left shoulder and left arm are slightly depressed and screwed forward, the latter being folded or bent upwards. The right hip and right leg, on the contrary, are slightly elevated and screwed forward, the latter being extended. The right hand is open and the left one firmly closed. The hands and feet are depicted with extraordinary skill, even in matters of detail; the latter being firmly planted on the ground.

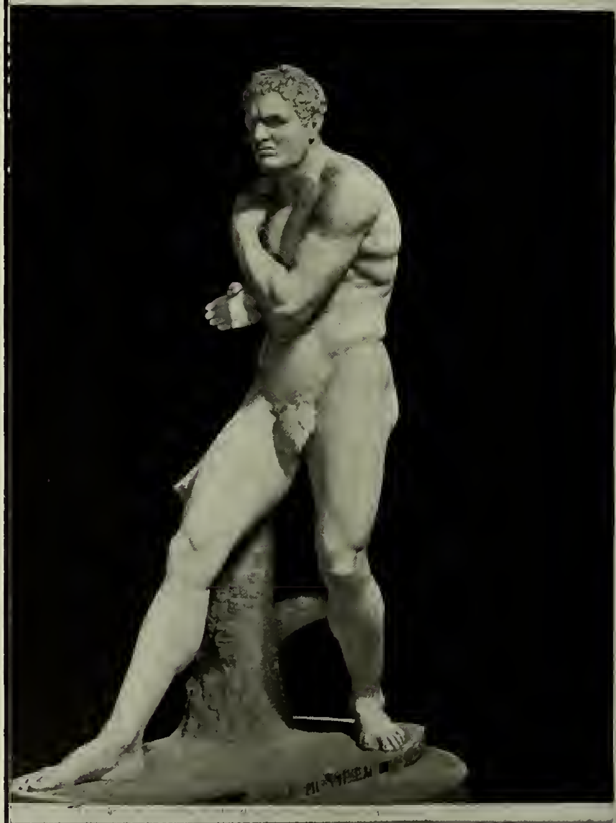
Fig. 4.—One of the two far-famed antique bronze statues of the Discoboli, or disc-throwers, from Herculaneum (Discobolo in atto di aver lanciato il disco—Naples, Museo Nazionale). As there are two of these statues, the one being the converse or opposite of the other, many are of opinion (and I incline to their view) that the disc-throwers are in reality athletes about to engage in a wrestling combat. The very lifelike disc-thrower—or, as I prefer to describe it, wrestler—still further illustrates and emphasises the screwing occurring at the shoulders and hips, and the synchronous, diagonal, forward movements of the right shoulder and right arm, and the left hip and left leg. The wrestler, as indicated, is one of two renowned statues—the other statue closely resembling the one here given and facing it. The statues represent two athletes bending forwards and approaching each other with the object of closing and getting into grips. Each athlete is eagerly and anxiously watching his opportunity to seize his opponent, and the arms and legs are in the best possible position for that purpose. The right arm is advanced and flexed, and the fingers of the right hand are spread out in eagerness to grasp and lay hold ; the left leg is slightly bent and the left foot firmly placed on the ground. The left arm and fingers also indicate a desire to seize ; the right leg being nearly straight, with the toes firmly planted on the ground and affording additional support.

[1] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom" (*Trans. Linn. Soc.*, vol. xxvi.). See also "Walking, Swimming, and Flying" (Anglo-American Science Series, 1873).

PLATE CLXXX

1

2



3

4

PLATE CLXXXI

(Ed.ne Alinari) P.e I.a N.o 11156 NAPOLI - Museo Nazionale. Venere Vincitrice. (Scultura Antica.)

1

(Ed.ne Alinari) P.e I.a N.o 11078 NAPOLI - Museo Nazionale. Flora Farnese. (Scultura Greca.)

2

(Ed.ne Alinari) P.e I.a N.o 11234 NAPOLI Museo Nazionale Mercurio in riposo (Bronzo Greco.)

3

547 MARCO AURELIO

4

PLATE CLXXXI

Plate clxxxi. contains photographs of four celebrated antique statues (one of them equestrian) in marble and bronze. They are remarkable for their grace of deportment and lifelike vigour, and cannot be surpassed as specimens of ancient art. They are very valuable as showing that physical men and women and horses were as perfect two or more thousand years ago as they are to-day. They illustrate the diagonal screwing movements at the shoulders and hips described in Plate clxxx.

Fig. 1.—Antique statue in marble of Venus conquering (Naples—Museo Nazionale). This fine work has the lower portion of the figure draped, and is regarded by many as the finest of all the Venuses. It is certainly instinct with life, and the head, face, and figure reveal a beauty, refinement, and grace all their own. The drapery is remarkably well arranged. The twisting at the shoulders and hips referred to in Plate clxxx. is further illustrated and confirmed ; the right shoulder being depressed and the right shoulder and arm screwed forward; the left hip being depressed and the left hip and leg, which are concealed by the drapery, screwed forward. The right arm, which is lowered, is extended, and the four fingers pointing forwards and downwards; the left arm, which is raised and slightly flexed, has the hand partly closed. The limbs, head, face, and body are exquisite in their detail, and reveal a grace and beauty of outline not surpassed by any ancient or modern statue. Certainly no modern woman could surpass it. Physically it is perfect as a representative of humanity at its best.

Fig. 2.—Antique Farnese Flora in marble (Naples—Museo Nazionale). This fine statue was found in the baths of Caracalla, Rome, and is a work of the early Roman empire, probably a reproduction on a colossal scale of a much smaller Greek original. When found it was minus the head. arms, and feet. These have been judiciously and skilfully restored. The Farnese Flora as regards head, face, limbs, body, and drapery is unique. The drapery is witchingly transparent, and the position of the body and limbs leaves nothing to be desired. The left shoulder and left arm are advanced ; the latter being flexed and holding a bouquet of flowers. The right leg is advanced and extended. The right arm is nearly straight and partly withdrawn; the right hand raising and supporting a portion of the delicate drapery. The left leg is partly withdrawn and flexed. The body and lower limbs are seen through, and their fine proportions enhanced by, the marvellous drapery. The disposition and arrangement of the limbs is especially charming. The diagonal twisting at the shoulders and hips is well marked, and there is this peculiarity (and it produces an admirable effect)—the right arm is straight and the left leg flexed, whereas the left arm is flexed and the right leg is straight. There is, therefore, a striking contrast not only in the diagonal positions of the arms and legs, but also as regards the flexion and extension of the arms and legs on opposite sides of the body.

Fig. 3.—Antique bronze Mercury seated and in repose, found at Herculaneum (Naples—Museo Nazionale). The lifesize statue of "Mercury, the messenger of the gods," in a sitting position, is a work of very outstanding merit, believed to be Greek. The head and face are splendidly modelled, and the entire figure reveals a high type of physical man in early elastic manhood. The body is strong and finely curved, and the limbs powerful and delicately outlined; the hands and feet being exquisitely formed. The repose and grace of the figure are mainly due to the position and shape of the limbs. These are all more or less flexed. The left shoulder and arm are screwed forward and the left hand partly closed: the right hip and right leg are also screwed forward—the leg being semi-flexed, and the foot, which is furnished with a pair of wings, being extended. The right foot is particularly fine. The right shoulder and arm occupy a posterior position, the arm being nearly straight, with the hand spread out and resting on the rock on which Mercury is seated. The left hip and leg also occupy a posterior position, the leg being flexed at nearly right angles and the left foot (also supplied with wings) being deposited on the rock supporting the statue. The left foot, like the right one, is a marvel of workmanship, and shows the fine curves peculiar to this important part of the body. The foot, as explained elsewhere, reveals two arches ; the one extending in the direction of the length of the foot, the other in the direction of the breadth of the foot.

Fig. 4.—Colossal bronze equestrian statue of Marcus Aurelius on the Capitol, Rome. This great equestrian statue occupies a foremost place in works of this order. The emperor and his horse are amazingly lifelike and real. The horse especially is full of animation and power. The disposition of the limbs of the horse is particularly interesting, as it indicates very distinctly the diagonal twisting of the shoulders and fore legs, and of the hips and hind legs. The right fore leg and the left hind leg are flexed and advanced diagonally; the right fore leg being off the ground and the left hind leg leaving it in the act of making a step. The left fore leg and the right hind leg, on the contrary, are extended and solidly placed on the pedestal of the statue ; the horse being supported diagonally, by the left fore and right hind legs respectively.

The position of the limbs is also accurately depicted in the famous equine bronze statues found at Herculaneum and deposited in the national museum at Naples. There are, of course, many other positions taken up by the legs of the horse in walking, but the diagonal positions referred to are the most outstanding. They are figured and described at length in living horses, &c. Malpositions in the limbs of equestrian statues completely mar the exceeding grace of movement, in a sense, peculiar to the horse.

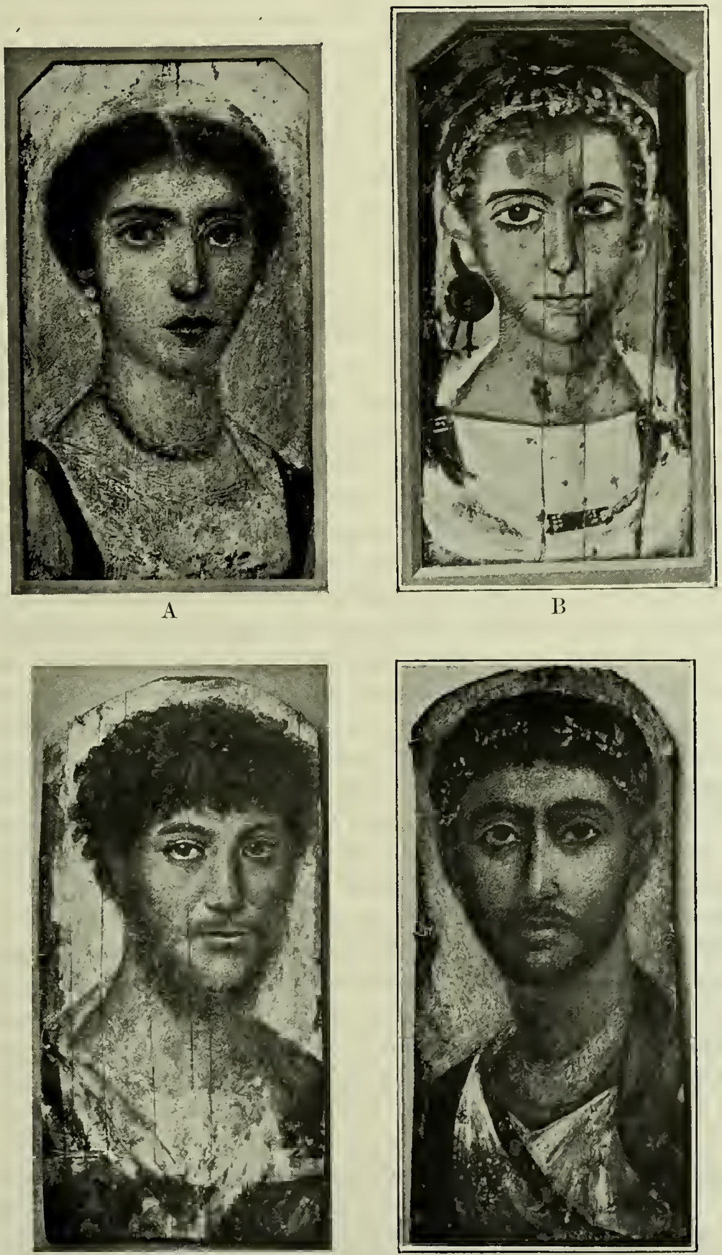
If the sculptured treasures of ancient Greece and Italy are to be trusted, it is quite evident that man has not altered or improved physically for over 2000 years. If, moreover, the size and configuration of the head, and the shape and expression of the face, have any physical value, it may be questioned whether intellectuality and ideality have, in modern times, attained a higher standard.

As the Greeks and Romans are known to have worked from living models, the figures portrayed in Plates clxxix. to clxxxi. may very fairly be regarded as reproductions of actual men and women who lived two or more thousand years ago. Of course, it suits Darwinians and evolutionists generally to say that 2000 or 3000 years are altogether inadequate to produce even slight changes in physical and mental man, but I would strongly urge that if no change, not even the most trifling, has been produced in the long period in question, it is for them to prove that modifications, alterations, and improvements have occurred, or can occur, in any longer periods. If the theories of "natural selection" and "evolution" have even the elements of truth in them, two or more thousand years should suffice to indicate the nature, if not the amount, of these modifications, alterations, and improvements. As already stated, no change whatever can anywhere be detected. If, however, perfect men

and women existed over 6000 years ago, and no trace of advance can be detected during that long period, it goes without saying that the onus of proof to the contrary rests with the "evolutionists." They assert that man is descended directly from the apes, and indirectly from the mollusc or something lower, by infinite permutations in infinite time. To prove their theory unlimited change and unlimited time are postulated. By basing their contention on unlimited change in unlimited time they remove the subject practically from the realm of human thought, and beg the question. If no visible change has occurred in man for over 6000 years he must be credited with a remarkable degree of persistency, and the argument that he is an original creation and *type* is greatly strengthened, if not wholly confirmed.

What is here said of the persistency of man is true of the great majority of animals depicted in the ancient Assyrian, Babylonian, and other sculptures, and in the frescoes of Egypt under the Pharaohs.

While a certain proportion of the sculptures and frescoes are fanciful, and represent griffins, winged sphinxes, winged bulls, centaurs, &c., quite a large number of them are carefully drawn pictures, evidently from the life. They can, for the most part, be readily referred to their originals. This is especially true of the ungulates; the portraits of the carnivora being more difficult to determine. Thus Mr. R. Lydekker,[1] to whom zoology is indebted for many important contributions, has been able to identify quite recently the following well-known animals, occurring on the east wall of the Chapel of Ptahhetep: "The ibex (*Capra nubiana*), the aoul, or Soemmerring's gazelle (*Gazella soemmerringi*). This gazelle is fairly abundant in Upper Nubia at present, and in past times was probably found much lower down the Nile Delta. The lesser kudu (*Strepsiceros imberbis*). The lesser kudu is not now found in Egypt, although it occurs in Somaliland and Abyssinia. The addax (*Addax nasomaculatus*), an antelope found at the present time in considerable numbers in the desert tracts of Northern Africa—the white or sabre-horned oryx (*Oryx leucoryx*), also found in the North African deserts. The white oryx is still a common antelope in the deserts of Upper Nubia and Kordofan.



A B C D

Fig. 580.

"Antelopes of other kinds, including some of the smaller gazelles, are recognisable on various Egyptian frescoes, but their exact specific determination is difficult. Cattle are frequently depicted, but all appear to be domesticated animals, none of which belong to the humped breed, now so common in Africa. Camels are occasionally represented, but there is nothing to show that these indicate the existence of this animal in a wild state in the country at that date; most probably, indeed, they are domesticated specimens. [It should here be noted that the tame condition of cattle and camels in early Egyptian times confers on these animals a greatly increased antiquity; the taming process extending over considerable periods.] Very interesting, in a scene representing tribute-bearers from Cush (Goss's 'Ancient Egypt,' p. 37), is the portrait of a giraffe with a dog-faced baboon clinging to its throat. Curiously enough, the giraffe is represented with the legs spotted right down to the

[1] "Some Ancient Mammal Portraits." (*Nature*, June 30, 1904.)

hoofs, after the fashion of the southern races of this species, and unlike the Nubian form, in which the spotting stops short at the knees and hocks.

"Among the carnivora the lion and the leopard are frequently depicted, but in the aforesaid frescoes of the tribute-bearers from Cush, the spots of the latter animal are represented as more like those of the ocelot. As might have been expected, the ichneumon, or Egyptian mungoose (*Herpestes ichneumon*), the snake-destroying propensities of which render it so venerated among the inhabitants of the Nile Delta, is very frequently represented in the frescoes. It is well shown in the Ptahhetep hunting scene. The fore-part of the animal in the same scene seems to be intended for the little African fennec-fox (*Canis famelicus*). The long-tailed and long-legged animal is apparently the lesser, or hairy-footed, jerboa (*Jaculus hirtipes*). Another rodent shown in some of the frescoes, as in one of labourers bringing in sheaves of corn (Goss, op. cit., p. 195), is the Egyptian hare. A remarkable instance of fidelity to nature occurs in the two portraits of a hedgehog in the Ptahhetep hunting scene, one of these representing the animal standing in the open, and the second showing it coming out of a hole with a locust in its mouth. The well-developed ears clearly show that the species depicted is the long-eared hedgehog (*Erinaceus auritus*)."

In addition to the foregoing, it may be stated that pictures of insects, reptiles, and birds, which readily admit of identification, occur in considerable numbers on ancient monuments, &c., in various parts of the world, all which go to prove that the persistency of type attributed to man extends to animals generally.

The "evolutionists" cannot reasonably claim unlimited modification and unlimited time either for the production of man or for the production of existing plants and animals. It is convenient for them to maintain that 6000 years is practically of no account in settling the much-debated question of the origin of existing plants and animals attributed by them to "natural selection" and "descent." The retort is obvious. If "natural selection" and "descent" produce no changes in 6000 years, what possible proof can be afforded that changes of a permanent character, even the most minute, are brought about in 12,000 or 24,000 or any greater number of years? The theory of evolution as based on natural selection and descent is altogether in the air, and there it had better remain until facts instead of fancies are furnished by the advocates of the theory. It is too much to ask intelligent reasonable beings to suppress their thinking powers and take the theory of evolution, as based on natural selection and descent, on faith. Moreover, as I have shown elsewhere (section 42), there is, strictly speaking, no such thing as natural selection, and descent as the direct outcome of natural selection. Evolution is possible only in development and within types. It is not true as a progressive, continuous advance from lower to higher plants and animals, and parts thereof; or as an unbroken series of transformations having for their object the production of animals from plants, and plants from some unknown and undemonstrable form of undifferentiated protoplasm.

The unchangeable nature of the human race is all but established by the illustrations supplied in Plates clxxix. to clxxxi. already fully described. In corroboration of this I append four photographs of ancient Greek heads taken from mummy coffins in the Fayoum (Fig. 580, A, B, C, D, p. 1349).[1] They prove more or less conclusively that no change whatever, not even the most trivial, has occurred in the human body for two or more thousand years. They show that there has been no appreciable modification either in the head or face, and that the crania and countenances of the ancients were, in all respects, as perfect as those of modern men and women. The same is true of the entire human frame; that has undergone no sensible modification, alteration, or improvement during the period in question, the physique of the ancients being, on the whole, superior to that of modern men.

§ 457. Antiquity of Man from the Geological Standpoint.

Great as is the antiquity of man according to Egyptian, Chaldean, and other records, his age is immensely greater from the palæontological and geological point of view. The vast stretches of geologic time assign to man what many will regard as a fabulous antiquity. Geologic time cannot, unfortunately, be accurately determined, but enough is known to assign to prehistoric man a date undreamed of until the advent of geology as an exact science.

The palæontological and geologic evidence consists of fossil human and other remains; the strata in which they are found; the deposition in the strata of flint and other implements; incised bones, pottery, &c.; contemporary fauna and flora; the rate of deposit of deltas; the formation of rocks; the elevations and depressions of the earth's crusts; the erosion and denudation of the same; the varying distribution of land and water; climatic changes as indicated by alternate tropical, arctic, and temperate cycles; these extending over vast periods, &c.

[1] In 1888 there was sent to Europe a series of funereal pictures or portraits believed to be about 2000 years old, and executed in the so-called encaustic painting, which is now a rare, if not a lost, art. They are Grecian in character, and of Hellenic derivation, although discovered in the Fayoum district of Egypt. They owe their origin to the fact that a small Grecian colony had settled in the Fayoum who buried their dead in an Egyptian cemetery. They furnish very fine examples of Grecian features, and indicate permanence of types in ancient and modern races.

From the history of the earth it will be seen that plants were created before animals, and that the simpler plants and animals appeared first. It will further be seen, that plants and animals are arranged according to an ascending scale, and that man appeared comparatively late on the scene.

All the early remains of man's works, so far as discovered, are simple in character and rude. They, moreover, indicate a progressive advance. Thus they begin with chipped flints consisting of arrow and spear heads, knives, bone and other scrapers, hammers, hatchets, &c. For a long time the chipped flints were regarded as accidental. A careful examination and study of them, however, proved their human origin, as indicated by their increasing size, and the superior shape, finish, and workmanship of the more recent specimens. There was to begin with, a stone age ; then a copper age ; then a bronze age ; and then the iron age, which brings us down to modern times. As civilisation and the arts improved, the mastery over the materials employed in the chase, war, and domestic purposes became more and more apparent. Similar advance could be traced in the cave, shore, lake, and other dwellings ; also in the articles found in the kitchen middens or refuse heaps of primitive man. There is every reason to believe that man at the outset lived in the open, and fed on fruits, roots, and small animals which he could seize and destroy with impunity and without the aid of weapons. By-and-by he resorted to natural caves for shelter and protection. He became a cave-dweller. As the caves were few in number, and not always conveniently situated, he resorted to the seashore, where he could obtain shell-fish and other food, and to fresh-water lakes, in the shoal water of which he drove wooden piles on which he erected wooden huts or houses. The situation of the pile huts protected him from his natural enemies. He also occasionally built his huts in trees for a like purpose. The lake-dwellings, vestiges of which can be seen in many countries at the present day, formed considerable villages, and in the mud and subsoil where they occur, not only the remains of food, consisting of fruit, roots, fish, and other animals, but also domestic and other implements are found in considerable numbers. In the great kitchen middens on the seashore indicating the camping-ground of families, similar traces of man's existence and progress are met with. The cave-dwellings also furnish their quota of food remains and implements, and yield in addition human skeletons or parts thereof ; also rude carvings or drawings. By carefully examining and studying the food remains and implements found in the camping-grounds, and in the caves and rude dwellings of primitive man, it is possible to construct a record of his mode of life and his progress towards civilisation. The food remains associate him with the flora and fauna of certain geologic periods, and the implements, consisting in succession of wood, stone, copper, bronze, and iron, tell their own tales.

Man no doubt for long ages remained a hunter pure and simple—an occupation well calculated to sharpen his mother-wit. This is proved by his animal food consisting exclusively of various kinds of fish and wild animals, such as the wild boar, stag, cave-bear, hyena, rhinoceros, mastodon, &c. Later the bones of the ox, horse, sheep, and dog appear, indicating a pastoral life. Still later, wheat, barley, and flax are found, showing he had taken to agriculture. His progress at first, from the peculiar circumstances, and as was to be expected, was exceedingly slow. Not till man had acquired a knowledge of metals did he make satisfactory progress. His mastery over the metals introduced a new era, and practically gave him the whip-hand of the situation. This mastery supplied him with implements and weapons which enabled him not only to subdue the beasts of the field, but also the stubborn soil.

It is impossible to say at what period man discovered and employed fire. The time is no doubt infinitely remote, as traces of fire are found from the first in his camping-grounds, cave, and other dwellings, and on his vegetable food stuffs (nuts, acorns, &c.), and on the gnawed bones which occur in plenty. The possession of fire, coupled with a knowledge of metals, untied the Gordian knot of human civilisation. It displaced the sun-baked pottery and bricks, and gave a tremendous impulse to the arts of peace and war. Contemporaneous with these advances was the development and perfection of speech, which resulted in inscriptions and written language. The crowning discovery in human civilisation and progress was the printing-press, which recorded and stored up the knowledge of one generation and transmitted it as a free gift to each succeeding one, and so made knowledge cumulative. By means of written language and the printing-press tradition gave place to history, and progress in the highest sense was assured.

The history of modern man does not at present concern us. It is prehistoric, primeval man with whom we are dealing.

In considering prehistoric man it is not necessary to deal with the geologic periods known as Primary or Palæozoic, or Secondary or Mesozoic, and only to a certain extent with the Tertiary or Cainozoic, some believing that man existed towards the close of that period (Tertiary). It is with the Quaternary or Palæolithic and subsequent periods that we have more especially to do, as during these periods indubitable evidence of man and his works appears.

The periods in question were marked by important terrestrial and climatic changes, which visibly affected

the flora and fauna ; plants and animals being adapted to a temperate, a warm or tropical, and an arctic or cold climate.

There seem to have been two great glacial periods with intervening non-glacial intervals. During the period anterior to the so-called historic period, the climate, configuration of the land and sea, and the prevailing flora and fauna underwent next to no change. This period is known as the Neolithic, and is transitionary in the sense that it is characterised by polished stone implements, the descendants of the earlier and ruder chipped flints : it also reveals copper, bronze, and iron implements ; the latter connecting it with the historic period. The Neolithic is sometimes called the recent or post-glacial period, from the fact that it marks the disappearance of the last great glaciation, and ushers in climatic conditions not unlike those prevailing at the present day.

The Palæolithic, Pleistocene, or Quaternary period preceded and is older than the Neolithic. In it unmistakable evidencc of man's existence can be traced in various directions. It is characterised by a flora and fauna in which existing species are mixed up with extinct species. The Palæolithic period has been, in a general way, designated the glacial period.

The Ternary period, comprising the Pliocene, Miocene, and Eocene periods, in turn preceded the Palæolithic, Pleistocene, or Quaternary period. It reveals doubtful traces of man, and is characterised by older and more generalised types of plants and animals in an ascending series.[1]

The secondary period is still earlier. In it the mammals are represented by a few weakly marsupials.

The primary period is the oldest of all, and contains only the earliest plants and animals.

Before considering the several periods to which reference has been made, it may be useful to say a few words regarding the cosmic and other changes which ushered them in, the causes of these changes, and the manner of measuring geologic time.

The glacial and post-glacial periods, extending over practically illimitable time, have produced extraordinary alterations on the earth's surface, and have considerably influenced the flora and fauna. The duration of the post-glacial period is believed to have greatly exceeded that of the historic period (10,000 years), and the duration of the glacial period is supposed to have very greatly exceeded that of the post-glacial period.

The glacial period varied in intensity, and was characterised by intermissions. Glaciation is not altogether a question of mere continuous cold ; glaciers being formed by alternations of heat and cold at longer or shorter intervals, extending over long periods.

There are various theories as to the production of glaciation, such as the varying distribution of sea and land, latitude, the prevalence of hot and cold air and oceanic currents, variations of solar and terrestrial heat, the eccentricity of the earth's orbit, precession, the position of the poles, &c.

The two theories most favoured are those propounded by Sir Charles Lyell and Mr. Croll : the former attributing it to a different distribution of sea and land, accompanied by changes in the air and ocean currents ; the latter to the effects of precession in conjunction with high eccentricity of the earth's orbit.

Proofs of the elevation of the land are furnished by the raised sea beaches with their complements of shells, and proofs of depression are provided by submerged forests. The effect of aërial and ocean currents in raising or lowering the temperature is well known, and has only to be mentioned to be appreciated.

Mr. Croll's astronomical theory of glaciation is deserving of consideration, but it can scarcely be regarded as the sole cause.

The changes produced by glaciation and by air, ocean, and other currents can scarcely be exaggerated. Air currents denude immense stretches of land to great depths, and ocean and other currents excavate deep fiords and valleys. Glaciers in motion completely alter the face of a country by grinding and grooving its surface, and by carrying and transporting untold quantities of débris in various directions, and to great distances. In glaciation, and in the cold and heat which accompany air, ocean, and other currents, we have forces capable of completely altering the aspect of the earth from time to time, and influencing and changing, within limits, the flora and fauna. These forces break up, triturate, and transmit in various directions, and to great distances, the substances forming the earth's crust. They are the active agents in determining the appearance presented by the earth and its flora and fauna in given localities at given periods. Their appearances are not to be confined to the present aspect and order of things. Old-world rivers existed before the present rivers, and air currents and extensive denudations set their seal upon an old-world geography. The rocks have, in many cases, been formed, broken up, and reformed, and deltas laid down and taken up and obliterated more than once. When the land is raised above the snow line it at once lends itself to glacial influences : when it is depressed, it lends itself to an opposite state of things. In all probability the depression is caused by the enormous masses of ice by their sheer weight indenting the crust of

[1] Professor Ameghino has announced the discovery in the lower Tertiary (Eocene of Patagonia) of several small monkeys of the American type of Cebidæ which furnish evidence as to the existence of anthropoid primates at this extremely remote date.

the earth, and so letting in the sea, which, in turn, induces a milder climate. The elevation and depression of land, simultaneously or alternately, necessarily alter the distribution of land and sea. Large continents are broken up in whole or in part, and islands take the place of continuous land. New oceans, inland lakes, and rivers are formed, and the flora and fauna are scattered broadcast to an extent difficult to realise. If to the cosmic activities referred to a practically unlimited time be added, it is not difficult to account for things as we find them, both in the inorganic and organic kingdoms.

While the original highways for the distribution of plants and animals over the surface of the globe have been largely destroyed in modern times, they existed long enough to effect their purpose, and there is reason to believe that some of them will be re-established in the fulness of time. The hippopotamus and rhinoceros are supposed to have found their way to Britain by ancient rivers and overland routes destroyed ages ago.

The great glacial period corresponding to the end of the Pliocene or the beginning of the Quaternary period was too universal and extensive to be accounted for by local causes. It affected practically the whole earth's surface.

"Ice-caps radiating from Scandinavia crept outwards, filling the North Sea, crossing valleys and mountains, and covering with their boulders and moraines a wide circle, embracing Britain down to the Thames Valley, Germany to the Hartz Mountains, and Russia almost as far east as the Urals. In North America a still more massive ice-cap overflowed mountain ranges 3000 feet high, and covered the whole eastern half of the continent with an unbroken mantle of ice so far south as New York and Washington.

"The first period of elevation and of intense glaciation passed away, and was succeeded by one of depression and of milder climate. . . . Marine shells at the top of what are now high hills, and which during the great glaciation were probably higher, attest the fact that a large amount of land must have been sunk below the sea towards the close of the first glacial period. It is equally clear that a long inter-glacial period ensued, during which many changes took place in the geographical conditions and in the fauna and flora, requiring a very long time. Thus Britain, which had been reduced to an Arctic Archipelago, in which only a few of the highest mountain peaks emerged as frozen islands, became united to the Continent, and the abode of a fauna consisting in great part of African animals. At one time boreal shells were deposited, at the bottom of an Arctic ocean, on what is now the top of Moel-Tryfen in Wales, a hill 1300 feet above the present sea-level; while at another the hippopotamus found its way, in some great river flowing from the south, as far north as Yorkshire, and the remains of African animals such as the hyena accumulated in our caves. In Southern France we had at one time a vegetation of the Arctic willow and reindeer moss, at another that of the fig-tree and canary-laurel. When we consider that little if any change has occurred, either in geographical conditions or in fauna or flora, within the historical period of some 10,000 years, it is difficult to assign the time which would be sufficient to bring about such changes by any known natural causes." [1]

The glacial and intervening periods covered an enormous lapse of time. This is proved by the comparatively very slow rise and fall of land. In Sweden cases of elevation and depression are occurring at present at the rate of about two and a half feet in a century, and Sir Charles Lyell estimates that at this rate an elevation of 2000 feet, followed by a similar depression, would occupy a period of 160,000 years. Of course, in certain volcanic regions, and where cataclysms may have occurred, the period would be considerably shorter.

Additional proof of the immense antiquity of the glacial period is afforded by the gradual production of the loess, a deposit of fine glacial mud similar to that obtained from the sediment of tranquil sheets of muddy water such as are supplied by the annual inundations of the Nile in Egypt. The loess fills up to great depths many of the valleys of Europe, Asia, and America, and even overflows the adjacent table-land.

Sir Charles Lyell estimates the thickness of the loess in the Rhine Valley at 800 feet. If the present deposit of Nile mud, which is about three inches per century, be taken as a criterion, the 800 feet of loess in the Rhine Valley would have required 320,000 years for their formation.

The loess is not confined to Europe, but is found in all regions where rivers have flowed from territories formerly covered by ice and snow. It occurs in the valleys of the Mississippi and Yang-tse-Kiang. In the loess of the United States, and in drifts presumably older, human remains have been discovered. Similarly, in the loess of Europe human skulls, skeletons, and implements have been found at considerable depths, mixed up with the remains of the mammoth and other extinct animals.

Sir Charles Lyell (as Mr. S. Laing points out),[2] when considering the fossil human bone found in the loess at Natchez, observes: "My reluctance in 1846 to regard the human fossil bone as of post-Pliocene date arose, in part, from the reflection that the ancient loess of Natchez is anterior in time to the whole modern delta of the Mississippi. . . . If I was right in calculating that the present delta of the Mississippi has required, as a minimum of time, more than 100,000 years for its growth, it would follow, if the claims of the Natchez man to have co-existed

[1] "Human Origins," by S. Laing. London, 1902, pp. 278, 280 and 281.

[1] Op. cit., p. 284.

with the mastodon are admitted, that North America was peopled more than a thousand centuries ago by the human race."

Additional proofs of the immense antiquity of primeval man are afforded by the amount of denudation and erosion which has occurred since the disappearance of the ice age, and the land and sea have acquired their present levels and general outlines.

Dr. Evans in his work, "Ancient Stone Implements," when referring to the ancient flints found at Bournemouth 100 feet above the present level of the sea, remarks : "Who, standing on the edge of the lofty cliff at Bournemouth, and gazing over the wide expanse of waters between the present shore and a line connecting the Needles on the one hand and the Ballard-Down Foreland on the other, can fully comprehend how immensely remote was the epoch when what is now that vast bay was high and dry land, and a long range of chalk downs, 600 feet above the sea, bounded the horizon on the south ? And yet this must have been the sight that met the eyes of those primeval men who frequented that ancient river, which buried their handiworks in gravels that now cap the cliffs, and of the course of which so strange but indubitable a memorial subsists, in what has now become the Solent Sea."

Similar erosions, but on a much more extensive scale, separated England from France. That the British Isles were originally connected with the Continent and until comparatively recent times admits of easy proof.

Dr. Evans' view is strikingly confirmed by Mr. Harrison, who found considerable numbers of palæolithic implements in the upland gravels in Kent and Surrey at even 750 feet above sea-level. These gravels include a wide area, and their elevation is such as to preclude the possibility of their being deposited by recent rivers. They must have been deposited ages before the present rivers began to scoop out their valleys, and when the configuration of the country was quite different. This follows because they occur at elevations greatly exceeding those of existing water-sheds and valleys.

Professor Prestwich, who investigated this subject very carefully, came to the conclusion that these implement-bearing gravels must have come from a mountain range 2000 or 3000 feet high, which formerly ran down the present weald of Kent, and which has been worn away by sub-aërial denudation to the existing low forest ridge ; the amount of denudation being probably not less than 2000 feet. The average rate of denudation, as approximately estimated by calculating the solid matter brought down by rivers, is about one foot in 3000 years. Judged by this standard the removal of 2000 feet of the Wealden ridge must have occupied about 6,000,000 years. This is probably an excessive estimate, as on hilly ranges and under glacial conditions the denudation would be much more rapid than under ordinary circumstances. Still, the time occupied in the process must have been extraordinarily great.

Professor Prestwich believes the high level or southern drift to be older than the Westleton drift forming part of the upper Pliocene series in Suffolk and Norfolk. If so, the existence of Tertiary man is in a measure confirmed ; the Palæolithic implements, which are of a very rude type, occurring in an earlier stage than those found in an undoubted Pliocene bed. Professor Prestwich, in a paper read to the Anthropological Society in 1892, sums up as follows : "Looking at the very distinctive features of those plateau implements, such as their rudeness of make, choice of material, depth of wear and staining, peculiarity of form—taken in conjunction with the extreme rarity of valley forms—they constitute characters so essentially different from those of the latter implements, that by these characters alone they might be attributed to a more primitive race of men ; and as this view accords with the geological evidence, which shows that the drift-beds on the chalk plateau with implements are older than the valley drifts, I do not see how we are to avoid the conclusion, that not only was the plateau race not contemporary with the valley men, but also that the former belonged to a period considerably anterior to the latter—either an early glacial or a pre-glacial period."

The antiquity of the Quaternary age is confirmed by discoveries in the New World. Thus the auriferous gravel deposits of California consist of huge masses of débris washed down by glacial or pre-glacial rivers from the western slopes of the coast range. This débris is mixed up with lavas and tuffs in layers, the products of pristine volcanic eruptions, and topped with a thick covering of basalts.

In the process of gold mining the several strata are tapped by deep shafts and tunnels, and the gravels of the pre-glacial rivers exposed ; these yielding stone implements of undoubted human origin. Mr. Skertchly, commenting on these gravels, says,[1] "Whatever may be their absolute age from a geological standpoint, their immense antiquity historically is beyond question. The present great river system of the Sacramento, Joaquin, and other rivers has been established ; cañons 2000 feet deep have been carried through lava, gravels, and into the bed rock ; and the gravels, once the bed of large rivers, now cap hills 6000 feet high. There is ample ground for the belief that these gravels are of Pliocene age, but the presence of objects of human formation invests them with a higher interest to the anthropologist than even to the geologist."

In this connection it is well to direct attention to an extraordinary find in North-western America, namely,

[1] Op. cit., pp. 291, 385, and 386.

the Nampa image or statuette, which is scarcely an inch and a half long, but reveals very considerable artistic skill. The image is thus described by Professor Wright: "The Nampa image was. brought up in boring an artesian well, at Nampa in Ada County, Idaho, through a lava-cap 15 feet thick, and below it about 200 feet of the quicksands and clays of a silted-up lake, formed in a basin of the Snake river, which joins the Columbia river, and flows into the Pacific, forming part, therefore, of the same geographical and drainage system as the Californian gravels. At this depth the borers came down to a stratum of coarse sand, mixed with clay balls at the top, and resting at the bottom on an ancient vegetable soil, and the image came up from the lower part of this coarse sand. . . . It was found to be modelled from stiff clay, like that of the clay balls found in the sand, slightly if at all touched by fire, and incrusted, like those balls, with grains of oxide of iron, which Professor Putnam considers to be a conclusive proof of its great antiquity. Mr. Emmons, of the State Geological Society, gives it as his opinion that the strata in which this image is said to have been found is older by far than any others in which human remains have been discovered, unless it be those under Table Mountain, in California, from which came the celebrated Calaveras skull."

The evidence of the existence of Tertiary man furnished by the Old and New Worlds, it will be seen, is very considerable.

It is not necessary to pursue this subject further: suffice it to say that the time is very much greater than was suspected even a few years ago.

A question of great importance here emerges as to the different races of mankind at present existing on the earth. Are these referable to a common origin in a particular locality, or to several origins in different localities. The former is the more probable. It is more reasonable to suppose that man had a common origin, and spread, carrying with him the peculiarities which distinguish him from all other animals, than that he was born in several centres, and converged to form a common humanity. Both opinions are held. Agassiz believes in separate creations in different localities; each creation being adapted to a particular habitat. However produced, man has from the first displayed the most extraordinary permanency and persistency. He is to-day precisely what he was 9000 or 10,000 years ago, as proved by paintings, carvings, &c., on ancient Egyptian tombs and monuments. Four varieties or races of man are depicted on the tombs and monuments in question, namely, the Negro, the Mongolian, the Arab, and the Caucasian. To these some are disposed to add the copper-coloured races of America and the Pigmies of Africa.[1]

All these varieties and races of men can and do intermarry and are fertile, proving that they are in reality only one people. The unchangeable nature of man for 9000 or 10,000 years (the historical period) is wholly opposed to his descent by "evolution" and "natural selection." Evolution and natural selection necessitate endless modifications, which, so far as is known, are wanting in his case. The essential links, though assiduously sought for, are not forthcoming.

Those who believe in multiple creations ask the evolutionists by what methods and by what routes could such unity and oneness as we behold in physical and mental modern man have been produced? Multiplicity of origins, they assert, is fatal to evolution and natural selection. Mr. Darwin fully realised this difficulty, and in a letter to Mr. Bentham endeavoured to anticipate it, and in so doing speaks of *unconscious* selection by man, and begs the question. He says, "I dispute whether a new race or species is necessarily or even generally descended from a single pair of parents. The whole body of individuals, I believe, became altered together—like our race-horses, and like all domestic breeds which are changed through 'unconscious selection' by man."

How, it may be asked, can man select unconsciously? If the idea of a common origin from a single primordial germ be departed from, and secondary origins or centres substituted, the whole fabric of evolution is destroyed. It is a case of blowing hot and cold at the same time. Secondary or subsequent centres of development are, under the circumstances, inadmissible.

What is true of the origin and descent of man is also true of the origin and descent of a large number of domestic and wild animals, also depicted on ancient Egyptian tombs and monuments. Like man, these animals have in no respect changed during the 9000 or 10,000 years which constitute the historical period. With these facts before us it is very difficult to avoid believing in the creation of types in time and space; the types being at once the centres of departure for slight variations in plants and animals, and the rallying or converging points to which they return when they revert and breed back, which they infallibly do, and so secure the permanency

[1] Professor Huxley classified the historic and pre-historic races of Europe as follows:—

1. Blond long-heads of tall stature, who appear with least admixture in Scandinavia, North Germany, and parts of the British Islands.
2. Brunette broad-heads of short stature in Central France, the Central European Highlands, and Piedmont. These are identified with the Ligurian race, and their most typical modern representatives are the Auvergnats and Savoyards.
3. Mongoloid brunette broad-heads of short stature in Arctic and Eastern Europe and Central Asia, represented by the Lapps and other tribes of Northern Russia, passing into the Mongols and Chinese of Eastern Asia.
4. Brunette long-heads of short stature—the Iberian race.

of the types. There is no proof of indefinite departures from types, which there would be if man were descended from a soft-bodied, shapeless mollusc.

The great antiquity of man, coupled with the continuity of land in various directions in primeval times, would quite satisfy the theory that existing man was descended from a single pair. They would have had sufficient time and opportunities for spreading. This belief is strengthened by the fact that modern men differ very slightly from each other, and have practically undergone no change during the historic period, that is, for 9000 or 10,000 years. Such a state of things is inconsistent with the belief that he is descended by "evolution" and "natural selection" from a monad by a gradual process of modification. Of course 9000 or 10,000 years is an insignificant period when compared with the enormous stretches of geologic time: still, stability and permanency of type during that period goes a very long way towards disproving the theory that man is descended from the monkeys and other old-world quadrumana. Moreover, as stated, no link has been found connecting existing man with the man-like apes, and no modifications worth mentioning separate existing man from primeval man. Indeed the modifications are too trifling to deserve serious attention or consideration. They are chiefly confined to the configuration and size of the skull. Thus it is stated that the skull of primeval man is smaller, the bones thicker, the forehead flatter, the superciliary ridges (frontal sinuses) more prominent, the chin more receding, and the visage more projecting or prognathous. It is also said the long bones are less rounded than those of modern man. No solid argument can, however, be founded on the modifications referred to, as they are not peculiar to primeval man. They are found in the different races of men and individuals as they exist on the earth at the present time.

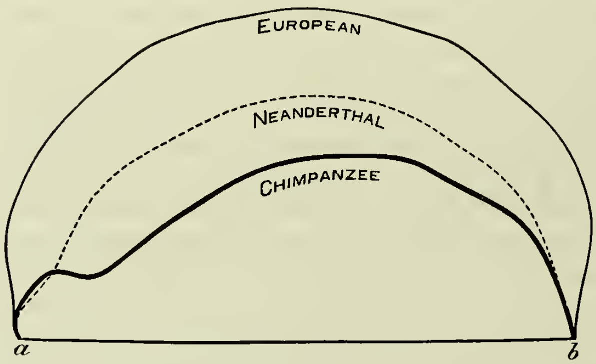


Fig. 581.

In this connection Mr. S. Laing in his "Human Origins" (p. 388) observes: "In the two best authenticated instances in which human skulls have been found in presumably Tertiary strata, those of Castelnedolo and Calaveras, it is distinctly stated that they present no unusual appearance, and do not go nearly as far in a brutal or pithecoid direction as the Quaternary skulls of Neanderthal and Spy, or as those of many existing savage races."

This points unequivocally not to a lower, but rather to a higher standard of man in Tertiary times. This view is quite consistent with what takes place in other and lower animals, namely, advance on the whole with occasional retrogression. The fact that civilised and savage man exist together now and existed together in times past may be taken to mean alternate advance and retrogression. It is known that while savage man in one region or country was fashioning his rude implements in stone, wood, and bone, civilised man in another region or country was constructing his copper, bronze, or iron ones. There are savage peoples still in their stone age, and it may be seriously debated whether these are not deteriorated peoples descended from a higher stock.

While the historical period of man dates back 9000 or 10,000 years, it must not be forgotten that at the beginning of this period a high state of civilisation existed, which means that many thousands of years must be added to allow for the progress then attained. The added period is necessary, unless man be regarded as a civilised being from the first.

Of course if the existence of Tertiary man and his rude flint and other implements be conceded, and if no proof of a contemporaneous civilised people be forthcoming, then the corollary is that savage man preceded civilised man. Even in this case, however, it does not follow that man is descended by infinite permutations in infinite time from the anthropoid apes.

The evolutionists admit that if man and the other quadrumana have a humble and common origin, that origin must be sought in the Eocene period which introduced the reign of the placental mammals. They can, however, afford no proof, direct or indirect, of his advent during the period in question. They also admit that no changes of any magnitude have occurred in man and the animals associated with him since the Quaternary period. Why this stasis?

The question of skulls has been treated comparatively by M. Debierre. He gives outlines of the skull of a chimpanzee, a supposed early human skull (the Neanderthal), and a recent European skull (Fig. 581).

The object is to show that the Neanderthal skull is nearer that of the chimpanzee than that of the modern European. Emphasis is laid upon the greatly developed superciliary ridges and low forehead of the Neanderthal skull, and the thicker bones and stronger muscular attachments. Against this is to be placed the fact that in

modern idiots the low forehead, and some of the other peculiarities noted, are present. The Neanderthal skull may possibly represent a diseased, degraded type of a higher race. The low forehead, moreover, does not necessarily represent diminished brain capacity. Some skulls with low foreheads are capacious. Lastly, brain-power is not to be wholly measured by mere volume. The quality as well as the quantity of the brain has to be considered.

Some authors divide the several races of men into long heads (dolichocephalic) and broad heads (brachycephalic); the former being usually associated with tall stature, the latter with short stature. Others classify them according to the texture and colour of the hair and skin, and the colour and shape of the eyes; others according to the facial angle, the shape of the jaw and chin, and the set and size of the teeth. These classifications, it need scarcely be remarked, are superficial and more or less arbitrary. They do not establish actual or real differences between the several varieties or races of mankind. This is proved by the fact that within the varieties or races as classified aberrant forms are constantly cropping up, showing that they are all referable to a common type.

Mr. Samuel Laing, who has devoted much time to this subject, in his "Human Origins" (p. 396) thus sums up: "Taking these prominent anthropological characters as tests, we find four distinct types among the earliest inhabitants of Europe, which can be traced back from historic to Neolithic times. They consist of two long-headed and two short-headed races, and in each case one is tall and the other short. The Dolichocephalic are recognised everywhere throughout Western Europe and on the Mediterranean basin, including North Africa, as the oldest race, and they are thought still to survive in the original type in some of the people of Wales and Ireland and the Spanish Basques; while they doubtless form a large portion, intermixed with other races, of the blood of the existing populations of Great Britain and Ireland, of Western and Southern France, of Spain, Portugal, Sicily, Sardinia, North Africa, and other Mediterranean districts. This is known as the Iberian race, and it can be traced clearly beyond history and the knowledge of metals, into the Neolithic stone age, and may possibly be descended from some of the vastly older Palæolithic types, such as that of Cro-Magnon."

It is extremely interesting to trace the progress of primitive man by means of his implements, utensils, dwellings, food, and other remains. The Scandinavian kitchen middens give us a glimpse of primeval man in the early Neolithic period. These are found in large numbers, and frequently of very great size, on the Baltic shore of Denmark. They are much older than the lake dwellings, and indicate a much ruder and more primitive stage of civilisation, similar to that existing among the Fuegians of the present day. They consist of vast accumulations of the remains of shell-fish (oysters, mussels, &c.), and of the bones of wild animals (fishes, birds, and mammals), all of existing species, with large numbers of flint and bone implements, and occasional fragments of coarse pottery. It has been surmised, from the presence here and there in the middens of the bones of the cod and other deep sea fishes, that the men of this period must have possessed boats and nets for the capture of the said fishes, but this is a mere guess. The possession of boats by the lake-dwellers is more certain, as canoes composed of logs of oak, beech, and other timber dug or burnt out of the solid are found ever and anon in the mud of lakes, rivers, and estuaries. The kitchen middens are in some cases 1000 feet long, 200 feet wide, and 10 feet deep. As they formed the refuse heaps of a very sparse population, probably only a few families, their formation must have occupied an enormously long period. The kitchen middens are not confined to Denmark; they are found on even a larger scale on the sea-coasts of Europe and America. Old as they undoubtedly are, their antiquity is, in a sense, modern when compared with the Palæolithic period.

A distinction is to be drawn between the food remains of the kitchen midden period and those of the Palæolithic. In the former the remains are those of existing species mixed up with rude pottery and polished stone implements; in the latter the remains are those of extinct animals; the pottery and flints being of a still more primitive description.

The peat mosses of Denmark, formed in hollows of the glacial drift, afford evidence of the early Neolithic period. These have supported three successive forest growths; the lowest being a forest of fir, that above it of oak, the most recent or uppermost that of beech.[1]

The implements found in the beech stratum are modern, those found in the oak stratum belong to the later Neolithic and bronze periods, those found in the fir stratum belonging to the earlier and ruder Neolithic, and resembling those occurring in the older lake villages and shell mounds. Here a relation can be traced between the flora of Denmark and the civilisation of its early inhabitants. Steenstrup is inclined to assign to the peat mosses of Denmark an antiquity of from 4000 to 16,000 years.

The Neolithic period revealed human remains in the arrow-heads found in Egypt, and in the fragments of pottery obtained by deep borings from the Nile; these, it is estimated, dating from 15,000 to 20,000 B.C.

While the Neolithic period greatly exceeded the historic period in duration, and covered an immense stretch

[1] Beech has been the common timber in Denmark for over 2000 years, a fact of some significance as indicating the much greater antiquity of the oak and fir forests.

of time, it was trifling when compared with the preceding Palæolithic period. This is proved by sections of implement-bearing materials occurring in strata, in caves and other situations. Thus in Kent's caverns the Neolithic implements are confined to a stratum of black earth from three to twelve inches thick, while the Palæolithic implements occur in strata of stalagmite, red cave earth, breccia, &c., which extend to a depth of from 12 to 15 feet. It is safe to assume that Palæolithic time was to Neolithic time as 12 to 1 at least. In this connection it is important to point out that while there is no breach geologically between the Neolithic and Palæolithic periods, the instances are rare and even doubtful of the remains of Palæolithic man and of extinct animals passing by gradual transitions into those of Neolithic and recent times. On the contrary, there is what may be regarded as a distinct break zoologically between the Palæolithic animals and modern animals. This is significant, as showing the prevalence of types in time and space. If there be a disappearance of connecting links between the Palæolithic and Neolithic and recent periods, the inference to be drawn is in favour of separate creations as against evolution in its widest sense.

The changes which have supervened since the Palæolithic or Quaternary period are important and far-reaching. They are measured by elevations and depressions of the earth's surface, and by the effects caused by the wind and water currents, which have practically produced the climate, flora, fauna, and geographical conditions which now obtain. Mr. Mellard Read, of the Geological Survey, estimates that a period of from 50,000 to 60,000 years was required to achieve these results. Mr. Read, speaking of the Mersey Valley, says it must have been at first carved out of a plain of glacial drift by sub-aërial denudation, that a depression occurred and let in the sea, that estuarine clays and silts accumulated, that an elevation raised the whole into a plain on which oak forests grew, that a second depression occurred and re-admitted the sea, that estuarine deposits resulted, and that finally the whole was raised a second time—all this before the historic period. At the time referred to, the German Ocean, there is reason to believe, was dry land, and the Continent of Europe extended beyond the Orkneys and Hebrides. Professor Huxley (in an article on the Aryan question) was of opinion that "At no very distant period the land of Asia Minor was continuous with that of Europe, across the present site of the Bosphorus, forming a barrier several hundred feet high, which dammed up the waters of the Black Sea. A large extent of Eastern Europe and of West-central Asia thus became one vast Ponto-Aralian Mediterranean, into which the largest rivers of Europe and Asia, the Danube, Volga, Oxus, and Jaxartes, discharged their waters, and which sent its overflow northwards through the present basin of the Obi."

The evidence supplied by the Old World confirms the belief of the great duration of the post-glacial period and the immensely greater duration of the glacial period itself.

Some are of opinion that the duration of the post-glacial period has been overstated. They base their contentions upon evidence supplied by the New World as regards the erosive power and recession of the Falls of Niagara. Sir Charles Lyell estimated that 35,000 years was required to cut back the gorge of Niagara seven miles, but they maintain that this could be accomplished in 10,000 years. They endeavour also to shorten the duration of the glacial period by stating that the advance of the glaciers in Greenland is more rapid than in Switzerland on which the older calculations were made. Against this Mr. N. S. Shaler, a recent American geologist, brings forward a strong argument based on the distribution of American vegetation. He maintains that the black walnut, pignut, hickory, and other trees have spread northward by means of seeds shed from boughs, and by rodents, and thus a period of 10,000 or even 20,000 years is wholly inadequate for this purpose.

It is not necessary to pursue this subject further. The fact that man existed in Palæolithic or Quaternary times is sufficient to establish his extreme antiquity. The only point that remains, and concerning which a few words may be added, is his permanency during the greatly extended antiquity assigned him. Has he changed physically, or is he to all intents and purposes the same being he was during the Quaternary period? The reply must be that he has not changed physically. As an animal he is exactly what he was then. He has greatly changed mentally, but this is another matter. A greater degree of differentiation in man's nervous system (especially his brain) does not make him a new or a different being. There are varieties of men and women, but they all belong to the same family, and they are all fertile with each other. The long occupation by man of certain localities and districts in tropical, semi-tropical, and temperate zones has induced slight modifications in him, as in plants and the lower animals, under similar circumstances, but these modifications are mere trifles when the great question of man's descent is considered. They for the most part, as already explained, apply to the colour and structure of the hair, the colour of the eyes and skin, the size and shape of the skull, the facial expression, stature, &c. They are differences of little or no account, and are quite inadequate as data for establishing specific distinctions; they can all be accounted for by the influence of climate, locality, and environment extending over long periods. That man has not changed physically either during the historical period or the known geological period affords a crowning argument as to his being an original, independent being—that is, a separate creation and type, apart

from the man-like monkeys supposed by evolutionists and those who advocate natural selection to be his remote ancestors.

The great brain-power of man, so much in excess of his animal requirements, as pointed out by Mr. Alfred R. Wallace, separates him in a marked manner from every form of man-like ape. The same is to be said of his faculty of speech, his capacity for fire-raising, his power of making and using tools and weapons, his capacity for clothing and educating himself, &c.

It has been said that the difference mentally between the different races of men (the most savage and most cultivated) is greater than between the lowest man and the highest ape, but this only proves that in nature the types approach each other ; they do not actually merge into each other. There is advance of the types and within the types ; there is no proof of actual coalescence or unbroken continuity, such as evolution and natural selection demand.

The whole history of man shows that he belongs to the animal kingdom, but his endowments are such as to place him in a category by himself. He forms the veritable coping-stone of that kingdom, and to him has been given power over all other animals. It has also been allowed him to subdue the soil, and use for his own purposes all known plants. He has also been permitted to dominate the inorganic kingdom (the world of matter and force), and to utilise all the resources of nature to an extent which gives him practically a sovereignty over everything, living and dead. With the acknowledged possession of these God-like powers can it be for a moment thought that man is the offspring of chance—an accidental being developed by accidental modifications from an accidental speck of protoplasm extending over infinite time by a mechanical process of " evolution " and so-called " natural selection " ? The unchangeable nature of man, no less than his extraordinary powers, wholly refutes such ideas. From the first, man has been assigned a leading rôle among the animals, and his place is, and has been, assured from all time. Everything about him bespeaks adaptation and design of the highest order, and he has in himself the warrant of a separate creation by a Creator of transcendent power.

It is man's nervous system, and especially his brain, which highly exalts him above all other created beings. This at once connects him with the animal kingdom as a whole and with the Framer of the Universe. He is of the earth earthy, but in his higher mental and moral attributes he approaches indefinitely near the Divine.

I have purposely abstained from quoting Holy Writ in the present connection, but the account given of the creation of man, and creation as a whole, in the Book of Genesis is not so puerile and inaccurate as many modern scientists endeavour to make out. With a liberal interpretation as to time, the order and nature of creation are succinctly and graphically stated, and cannot be unceremoniously thrust aside as of no value.

The distinguishing feature of man's sojourn on the earth is his permanency as a distinct type. Man is the same to-day as he was thousands of years ago. As a matter of fact, his features and bodily configuration resemble, in all their details, those of the ancient Egyptians portrayed on temples, tombs, and works of art.

Recent researches go to show that man was civilised even 9000 or 10,000 years ago, and during this long period various cults and forms of civilisation flourished and disappeared.

It may be assumed, therefore, that man was as perfect 9000 or 10,000 years ago as he is to-day. In other words, there is nothing to indicate change of form or feature during that long period.

The history of man unequivocally points to a civilised origin, that is, an origin removed from savagery, where the higher attributes of the mind were more in evidence than the lower ones. It is an assumption to say that the wickedness of man in the earlier stages of his history proves him to have been of savage origin.

Between man and his Creator there has always been, and is now, a mysterious bond of union. Man alone of all the animals is endowed with a spiritual principle which binds him more or less closely to his Creator. He is acquainted with life as it is and as it will probably be in the hereafter. In him the spiritual is greatly in excess of the material, and reaches a higher level.

Man's attributes in not a few instances resemble similar attributes in the Creator. There is a community of interest between the Creator or First Cause and His human protegé which cannot be traced, or is traced with difficulty, in the lower animals. In man the Creator finds His own image, broken no doubt, but having in itself the characteristics of humanity at its best.

The gulf between man and the lower animals is more a spiritual than a physical or mental gulf. The lower animals undoubtedly reason, but the reasoning of man is all comprehending, and is equal to grasping more or less completely all nature as revealed by the inorganic and organic kingdoms.

Man possesses up to a point the power of unlimited expansion : he can measure and map, more or less perfectly, whatever he sees. He even discovers and brings under the ken of his fellow men the positions and movements of distant stars.

Man is not in any sense the product of evolution. He is not compounded of an endless number of lower animal forms which merge into each other by insensible gradations and modifications from the monera up to man. He is not the outcome of consanguinity and descent, but an original being who had no parents, but who, nevertheless, had the power of reproducing himself in a typical or unchanged form.

He is possessed of attributes which are commensurate with the area of his activity on the earth's surface. His chief characteristic, as already indicated, is his persistency as a type. He is the highest of all living forms. The world was made for him and he for it. Complete harmony reigned from the first: there was no jarring, no incongruity, no suicidal opposition. Everything was made to fit and dovetail into every other thing. There was, moreover, no accident or chance. On the contrary, there was forethought, prescience, and design. There was freedom of action in certain directions, and limitations in others. Man was from the first a conditioned being. The conditions make him amenable to law and order in the ordinary sense; they account for fixity of type, the tendency and power to breed back, and for retrogression as opposed to progression.

Of course all that is said here applies equally to the ancient and modern condition of things: it brings everything into one great harmonious whole.

The earth, and man as the denizen of the earth, bear fixed relations to each other, and these relations are never opposed to each other, but work together to a given end and according to design. If the relations vary they only vary relatively, so that harmony between man and his Creator and Upholder is not destroyed.

In everything inside and outside of man design is writ large, and it appropriately forms the keynote of the present work.

APPENDICES

APPENDIX I

ANATOMICAL PREPARATION-MAKING

AS DEVISED AND PRACTISED AT THE UNIVERSITY OF EDINBURGH AND AT THE HUNTERIAN MUSEUM OF THE ROYAL COLLEGE OF SURGEONS OF ENGLAND[1]

Having of late years been frequently asked by anatomists, physiologists, surgeons, and others to give an account of my methods of making and preserving anatomical dissections for teaching, examination, and museum purposes, I feel it to be my duty to comply with the request. I should possibly have attended to this matter long ago, but did not deem it of sufficient importance to demand separate treatment. As, however, my anatomical and other friends think otherwise I have no option but to accede to their wishes. It will save time, and possibly add interest, if I treat the subject historically and from a personal point of view.

My connection with anatomy began in the winter of 1855, when I attended a course of anatomical lectures at the Royal College of Surgeons of Edinburgh under the late Dr. John Struthers, then teacher of anatomy at the Extra-mural Medical School of Edinburgh, and a most painstaking and enthusiastic anatomist. He subsequently became Professor of Anatomy at the University of Aberdeen, and did much to make the Aberdeen Medical School a success. Latterly he became my colleague at the Council of Medical Education and Registration of the United Kingdom, President of the Royal College of Surgeons of Edinburgh, and a knight of the realm. I did no dissection or anatomical reading under Dr. Struthers, as I had not then made up my mind to become a medical student, my chief object being to test my nerves as to anatomical procedure. I also this winter (1855) attended a course of natural history at the Free Church College of Edinburgh under the sagacious and thoughtful Professor John Fleming. The natural history lectures were a great source of pleasure to me, as I had always been fond of all kinds of natural objects, living and dead. The lectures of Dr. Struthers and Professor Fleming determined me to adopt medicine as a profession.

The winter of 1856 found me a fully fledged medical student at the University of Edinburgh. Here I came under the influence of quite a galaxy of genius and talent. The University of Edinburgh was then, and during my medical student days, in the zenith of its reputation as a medical school. The professoriate literally bristled with great names. There was not a single professor who had not written his name in large letters on the scroll of fame. John Hutton Balfour taught botany, George J. Allman natural history, William Gregory chemistry, John Goodsir anatomy, John Hughes Bennett physiology, James Young Simpson midwifery, Robert Christison materia medica, Thomas Traill medical jurisprudence, William Henderson pathology, James Miller surgery, James Syme clinical surgery, and Thomas Laycock the practice of physic. The teachers in the Extra-mural Medical School were scarcely less distinguished, and included the well-known names of Stevenson Macadam (chemistry), John Struthers (anatomy), William Sanders (physiology), William T. Gairdner and Warburton Begbie (practice of physic), James Spence, Patrick Heron Watson, and Joseph Lister (surgery), Alexander Keiller (midwifery), Daniel Haldane (pathology), and Douglas Maclagan and Henry D. Littlejohn (medical jurisprudence). There was keen rivalry between the University professors and the teachers of the Extra-mural Medical School. It was a case of diamond cut diamond.

There was, moreover, at the time of which I write much intellectual activity at both centres of medical education in Edinburgh. Great discoveries were being made and new methods of teaching and research were being adopted. Syme was dazzling the world by his bold, original surgery; Simpson was receiving one long, continuous ovation because of his discovery of chloroform; Bennett was inaugurating a new era in the teaching of clinical medicine by his habitual use of the microscope and his exact methods; and Lister was laying the foundation of a world-wide reputation by his researches on the blood and his investigations of rudimentary forms in their relation to antiseptics.

The intellectual activity and fame of the professors and extra-mural teachers at Edinburgh naturally attracted

[1] Reprinted from *The Lancet*, November 23 and 30, 1901.

medical students in great numbers, and these of the best. Here the case was one of action and reaction. The cycle of great thinkers and masters in their departments produced, as was to be expected, a cycle of great students, many of whom subsequently became eminent professors, teachers, physicians, and surgeons. The following among others were medical students at the University of Edinburgh in my day: Thomas Grainger Stewart, William Rutherford, John Duncan, Thomas R. Fraser, John Cleland, James Crichton Browne, Arthur Gamgee, Crum Brown, Thomas Annandale, Blair Cunynghame, Robert B. Finlay, Alexander Dickson, William Mitchell Banks, Andrew Smart, William C. McIntosh, Joseph Fayrer, Thomas Clouston, Kenneth Macleod, Argyll Robertson, James Little, John Anderson, Peddie Steel, John Young, and James Rorie.

The professors were held in the very highest estimation by the students, and while there was much honest rivalry between the latter there was also a genuine *esprit de corps* in all the classes and between seniors and juniors. This good-fellowship was extended and cemented by the meetings of the students at the Royal Medical Society, which took place every Friday evening during the winter session. The Royal Medical Society of Edinburgh, of which I was one of the Presidents, is quite the oldest, wealthiest, and most important medical students' society in the kingdom. It was founded in 1737, and incorporated by Royal Charter in 1778. It has its own buildings, consisting of a large, handsome debating hall, a very extensive library (20,000 volumes), chemical and botanical museums, reading-rooms, &c. Its ample and illustrious roll of ordinary members contains many of the greatest names connected with literature, science, and medicine, during the past 164 years; amongst others those of Mark Akenside, Oliver Goldsmith, William Cullen, Alexander Munro, James Gregory, Benjamin Franklin, Joseph Priestley, Percival Pott, Sydney Smith, Robert Liston, Mungo Park, William Sharpey, John Brown, Robert Christison, James Syme, John H. Balfour, Jonathan Pereira, James Young Simpson, John Goodsir, John Hughes Bennett, W. B. Carpenter, W. R. Sanders, Charles Murchison, W. H. Broadbent, Richard Owen, J. Matthews Duncan, and Joseph Lister. At the Friday evening meetings of the Society an original paper was read, and was keenly debated and discussed. This was the best training in the world for future public men. It taught them the forms of procedure, and gave them opportunities of speaking which were simply invaluable. After the debate tea and coffee were served, and the students returned to their rooms, exhilarated and refreshed, forgetful of the drudgery of the week.

The training at Edinburgh University in my time was more practical than bookish, and students were taught to think and to act for themselves as independent members of society. This developed character, and gave rise to originality of treatment in the various subjects handled. At the end of each winter session the Society gave a great dinner, to which the professors, extra-mural lecturers, the judges, town dignitaries, and celebrated men were invited. The relations between the students and the professors were of the most cordial description. Syme, Bennett, Simpson, and Goodsir were especial favourites. Syme captivated the students by his indomitable pluck and energy, and by his terse, vigorous way of putting things, as exemplified in his very admirable and much-prized surgical writings. I had the good fortune to be selected as one of his clinical surgical dressers, and subsequently as his resident house surgeon, and I owe him a deep debt of gratitude for many favours received. Syme was public-spirited and masterful, and stood up for the rights of the students on all occasions. He was the very embodiment of hospitality. Few *savants* visited Edinburgh who were not entertained by him in right princely fashion. He had as intimate friend and counsellor the celebrated Dr. John Brown, the author of "Rab and his Friends," "The Twa Dogs," "Horæ Subsecivæ," &c.

Bennett taught physiology with much acceptance, but it was as a great teacher of clinical medicine that he made his mark and out-distanced all competitors. His work on Clinical Medicine was of the nature of a revelation at the time it was written. He was noted for his great clinical acumen and slashing oratory, and, at times, for his scathing sarcasm. He was, notwithstanding, one of the kindest and most entertaining of men. As his class assistant for two years I knew him well.

Simpson was a great power in the University. He was justly celebrated for his originality and persuasive eloquence. His introduction of chloroform as an anæsthetic, God's choicest gift to suffering humanity, placed him on a pedestal all his own. His researches in obstetrics, acupressure, archæology, and other subjects carried his fame to all lands. Of him it could fittingly be said,—

> "He was a scholar, and a ripe and good one;
> Exceeding wise, fair spoken, and persuading."

Goodsir attracted the students by his studious habits, his transparent honesty of purpose, wide grasp, and lofty ideals. He was without doubt one of the greatest human and comparative anatomists Scotland has produced. He was deeply versed in cells, morphology, and teleology, and anticipated Virchow in much of his work on the first. He was profoundly learned, a philosopher of a high cast, intent on getting at the root of everything. His teaching was considerably above his junior students, but they, with the seniors, listened with rapt attention. He inspired

every one with his own enthusiasm and love of research. He devoted himself soul and body to his work, and for this sacrificed everything, even his health. He had, by continuous over-exertion, brought on paraplegia, as his co-professor in the chair of Logic, the celebrated Sir William Hamilton, had, by similar means, induced hemiplegia.

The late Professor William Sharpey of London told me on one occasion that Goodsir's habit was to read and to work late into the night, and instead of going to bed to throw himself on a sofa for an hour or two and then get to work again. While he was frail, very frail, on his feet, his head and hands were the head and hands of a giant. It was a touching sight to see him in his class-room steadying himself for a great effort—a grand generalisation in human or comparative anatomy, or a trenchant criticism of an unworthy or unprincipled opponent. In such cases his luminous grey eyes flashed, a little bead of foamy saliva gathered on his lips, and his arms, if free, went like flails. A storm of applause invariably followed these efforts. The enthusiasm and honesty of purpose of the man were catching, and ran through the students like electricity. If his students did not all succeed in completely following the great and original anatomist, they all revered and admired him, and none, however obtuse, came quite empty away.

Under Goodsir and his predecessors in the chair of Anatomy—the three Munros, especially Munro *secundus*—the Edinburgh School of Medicine had acquired a great reputation for its elaborate and highly finished dissections, a circumstance which contributed in no small degree to the production of a race of great Edinburgh surgeons. Goodsir and Munro *secundus* were especially celebrated for their superb vermilion injections of animal organs and tissues of all kinds, and no finer examples of such injections can anywhere be seen than in the Anatomical Museum of the University of Edinburgh. Goodsir was a great dissector and preparation-maker, and had a hearty and profound appreciation of carefully executed, finished dissections. He had large, powerful, finely shaped hands, and wielded the scalpel with a dexterity and grace truly remarkable. He had no patience with slovenly work, and his students had no excuse for being bad or even mediocre dissectors. He placed before them the finest models, not only in the dissecting-room, but also in the University Anatomical Museum.

It should here be stated that there is the greatest possible difference between the dry dissections seen in the dissecting-room and the wet dissections seen in the museum. An ordinary dissecting-room specimen, however well executed, if placed in water or spirit at once becomes a mass of untidiness and fluff. This follows because the fluid softens and floats out the cellular and other tissues, and reveals any accidentally cut fibres or flaws. The dissection made under fluid is infinitely more difficult, and it is only a master and expert in dissection who can make wet preparations. The time required to make a wet dissection is, moreover, six or eight times greater than that required to make a dry one.

As showing Goodsir's passion for dissection he exclaimed on one occasion, "I love the horse; I have dissected him three times." Goodsir and the Queen's famous sculptor for Scotland, John Steel, with whom I was intimate, dissected and took plaster casts of the horse together. These I have often examined and admired in Steel's studio. Goodsir had a high appreciation of the most beautiful and most spirited of animals, and drove the handsomest horses in Edinburgh.

Goodsir had under him, as Sub-curator of the Anatomical Museum and factotum, Mr. A. B. Stirling, one of the most remarkable men ever connected with a medical school. Mr. Stirling was a self-made, self-educated man, but naturally a gentleman. By great industry, constant application, and inherent ability, he overcame all obstacles. He could turn his hand to anything. He prepared and injected subjects for dissecting, macerated bones, articulated skeletons, took plaster-of-Paris casts, made glass cases and microscopic cabinets, mounted preparations, re-distilled foul spirit, and attended to the anatomical department generally. Latterly he developed quite a genius for injecting and making microscopic specimens. He was the first to provide microscopic slides on a large scale for students. These were sometimes injected and sometimes stained, and were, as a rule, wonderfully beautiful and illustrative. His spinal cord and brain specimens, of which I have a unique collection, were quite the largest and finest seen in his day. He was the original inventor of the microtome, or graduated microscopic section-cutter, and excelled all others in mechanical microscopic methods. By means of his microtome he made the thinnest microscopic sections on record. To his many accomplishments he added much tact and great kindliness of disposition. He was ever ready to help others, and his deferential, resourceful, responsive nature made him a great favourite.

I have dwelt upon Professor Goodsir and his able lieutenant because towards the end of my career as a medical student at the University of Edinburgh I was brought much into contact with both.

At the end of the winter session 1857–58 Professor Goodsir gave out as the subject of his senior anatomy gold medal for session 1858–59, "The Arrangement of the Muscular Fibres in the Ventricles of the Vertebrate Heart." This formed the veritable Gordian knot of anatomy, and had been a subject of dispute for some 200 years. Vesalius, Albinus, Haller, and De Blainville had all confessed their inability to unravel it. It certainly was a tough piece of work to ask students to undertake, but the problem was quite Goodsirian in character. It was involved

and knotty, but explanation there certainly was if it could only be dug out. Many of us stood aghast when the subject of competition was announced, but it gradually settled into our slow, persevering Scotch minds, my own amongst the rest, and became less formidable on closer acquaintance and as time rolled on, on the principle that "familiarity breeds contempt."

Like Don Quixote, I determined to have a tilt at the windmill. Having fortified myself with all the literature on the subject I could lay hands on, I left Edinburgh for my home in Lanarkshire. Arrived there, I eagerly scanned and mentally took note of everything written on the structure of the ventricles. The accounts given were meagre, conflicting, and so unsatisfactory that I resolved to investigate the subject *de novo.* I at once proceeded to dissect every kind of heart within reach and in large numbers. I also took the precaution of making careful drawings and notes of each dissection for future reference and comparison. The hearts chiefly employed, at the outset, were those of the sheep, calf, ox, and horse. I soon found that if satisfactory progress was to be made I must devise a new method of dissection, and it was at this juncture that my career as an original dissector and maker of preparations began. After frequent attempts and failures at hardening the ventricles of the heart by means of methylated spirits, chemicals, &c., I hit upon the expedient of stuffing and gently distending them with dry oatmeal (a truly Scottish procedure), and slowly boiling them for from four to five hours. This enabled me to get quit of all the external fat, blood-vessels, nerves, lymphatics, and cellular tissue. I then immersed the ventricles in proof methylated spirit for a fortnight or three weeks to harden them. I found that the ventricles so treated were in the best possible condition for dissecting, and that, as a matter of fact, I could separate and peel off the muscular fibres of the ventricles in layers as I would the layers of an onion. The new mode of dissection virtually gave me the whip-hand of the situation. I soon satisfied myself that not only did the muscular fibres of the ventricles form layers, but that the layers were of two kinds—namely, external and internal—and that the muscular fibres forming the external layers wound in a spiral direction from left to right from above downwards, while the fibres forming the internal layers wound in an opposite spiral direction from right to left from below upwards; that, in fact, the muscular fibres of the external and internal layers formed two sets of opposite spirals which crossed each other, the crossings becoming more oblique as the fibres constituting the central layers were reached. I subsequently discovered that the muscular fibres forming the external layers were divided into two sets of spirals (a right- and a left-handed set), and that the muscular fibres forming the internal layers were similarly divided into two sets and formed opposite and complemental spirals; the two sets of external spirals being largely continuous with the two sets of internal spirals at the apex and at the base of the ventricles and producing perfect symmetry, the symmetry being most marked in the left ventricle. The ventricles were evidently constructed on the lattice girder principle, where stays and struts are employed in every direction to give the greatest amount of strength with the least possible material. Here was an anatomical puzzle of the first magnitude. I was sorely perplexed, the more so as I found that the spiral external muscular fibres were, as stated, for the most part continuous with the spiral internal muscular fibres at both the apex and base of the ventricles. I paused and pondered, but no further light was vouchsafed. A lucky accident came to my assistance. One day I came down to dinner a little earlier than usual, and casually taking up a newspaper commenced to roll it layer upon layer obliquely from one corner as grocers do in making conical paper bags. I observed to my surprise that the lines of print on the several layers of the newspaper ran in different directions according to a graduated order; the lines of print on the outer layers running spirally from left to right downwards and becoming more oblique as the central layer was reached; the lines of print on the inner layers running spirally from right to left upwards and becoming more vertical as the central layers were receded from. The lines of print on the external and internal layers crossed each other at increasing angles, letter X fashion, as the central layer was approached. I observed further that the lines of print forming the external layers of the newspaper were continuous at the apex of the cone with the lines of print forming the internal layers of the newspaper, and that if I folded the internal layers of the newspaper outwards at the base of the cone the various internal lines of print corresponded in direction with the various external lines of print, producing continuity of the print at the apex and base respectively, as in the ventricles of the heart, and giving rise to a methodical but complicated series of figure-of-eight loops, the loops being directed vertically in the superficial layers and transversely in the deeper layers. A closer examination of the newspaper cone with its lines of print revealed a mathematical arrangement of marvellous complexity and beauty; the lines of print on the outside and inside layers of the cone making left and right spirals continuous at apex and base and gradually changing direction and crossing at more oblique angles as the central layer was reached.[1] Here was the whole thing in a nutshell. It was a case of the reading turning in or involuting at the apex and of the reading turning out or evoluting at the base. It was, in short, a mathematical problem of

[1] Two sheets of newspaper set at a certain angle and rolled into a cone, the one within the other, give the two sets of external spiral readings and the two sets of internal spiral readings running in opposite directions which produce perfect symmetry.

the most intricate yet simple description. I involuntarily cried, "εὕρηκα," as I instinctively felt that I had mastered the problem. The rest was easy. It was simply a matter of further dissection and accumulated proof.

When the beginning of the winter session (1858–59) came round I betook myself to Edinburgh with all my belongings in the shape of dissections, drawings, notes, &c. Arrived there, I at once cast about for fresh material. I ransacked the leading fish-shops and obtained the hearts of the cod, salmon, sunfish, fishing frog, and turbot. I was fortunate in securing the heart of a monster shark which was killed in the Firth of Forth. I also called at the large hotels and got several fine turtle hearts. I likewise procured the hearts of the tortoise and alligator. I further made raids on the poulterers, and got the hearts of the duck, goose, capercailzie, and turkey, and one splendid swan's heart.

The arrangement of the muscular fibres in the ventricles of the heart of the fish, turtle, &c., was simple and interesting, but did not throw much light on the complicated arrangement met with in the ventricles of the bird and mammal. The muscular fibres in the former follow a vertical, oblique, and transverse plicated direction with certain fibres running from without inwards, and the converse, in such a manner as to antagonise each other and to give rise to a porous, spongy condition of the interior of the ventricular wall, an arrangement calculated to confer great strength and to triturate and mix the blood where required. The arrangement of the muscular fibres of the ventricles of the bird was in every respect similar to that occurring in the ventricles of the mammal, with the exception that in the right ventricle of the bird a muscular valve took the place of the fibrous tricuspid valve in the mammal, a modification readily secured by the muscular fibres, which in the right ventricle of the bird fold over and are continuous at the base, splitting into two and forming a concave pouch—the concavity of which is directed downwards and towards the septum of the ventricles.

I dissected a comparatively large number of mammalian ventricles, including those of the sheep, calf, ox, horse, deer, pig, porpoise, seal, lion, giraffe, camel, and man. I found that as a whole the ventricles of the sheep gave the best results. I made in all 112 finished dissections and drawings of the ventricles referred to. These dissections and drawings were made in my lodgings in the small hours of the morning when my other work was over for the day, and none of my fellow-students knew that I was at work on the subject. Time passed rapidly, and when it was within a fortnight or so of the period fixed for giving in the dissections, drawings, and descriptions thereof I had still much to do. There was nothing for it but to work night and day, and this I did continuously for over a week. My dissections, drawings, and essay were labelled "*Per ardua*," Professor Goodsir and all others being ignorant of the author. The day for awarding the medal came round and the great anatomical theatre was crowded with some 400 students, all more or less on the *qui vive*. The professor's table was littered with dissections in flat glass jars immersed in pure spirit. There had evidently been a keen competition, and curiosity was raised to a high pitch because of the praise lavished upon some student as yet unknown. When the envelopes containing the mottoes of the competitors were opened I found to my surprise that I was the lucky one. A hearty round of applause followed the announcement, and every one seemed pleased. Professor Goodsir asked me to call on him next day, which I did. He was anxious that the heart dissections should be presented to the Anatomical Museum of the University of Edinburgh and mounted in separate glass jars as a collection. He also requested that I should do the mounting myself. I readily assented to both propositions, feeling that the dissections, if valuable, should be deposited in some public institution and be available for reference.

Specimen photographs of my dissections of the muscular arrangements of the ventricles of the mammalian heart are given at Plates xcvii. and xcviii., in the body of the work.

During the summer session of 1859 I permanently put up in neat glass jars, with glass tops designed by Professor Goodsir, my 112 original dissections. While so engaged I worked in one of Professor Goodsir's rooms, next to that usually occupied by Mr. A. B. Stirling. This was my first experience in mounting preparations permanently for museum purposes. Mr. Stirling imparted much useful information, and was very kind. He gave me my first lessons in injecting, showed me how to re-distil soiled spirit, to make and mount microscopic specimens, &c. I was greatly indebted to him in many ways, and had a sincere regard for him.

The higher dissection and preparation-making require much patience, skill, and delicacy of manipulation. They also require much time. I, however, loved the work. During the summer of 1859 I took photographs of my dissections in their jars on the roof of the anatomical department of the University of Edinburgh with a view to illustrate and remodel my essay in memoir form, "On the Arrangement of the Muscular Fibres in the Ventricles of the Vertebrate Heart," which was to be communicated to the Royal Society of London.[1]

In the autumn of 1859 Professor Syme, Professor Sharpey, and Professor Allen Thompson paid me a visit at the University of Edinburgh Anatomical Museum to inspect my dissections, and Professor Sharpey was so

[1] The memoir I find was communicated to the Royal Society of London by Professor John Goodsir on Nov. 22, 1859. It was published *in extenso* with five plates (72 figures) in the *Philosophical Transactions* in 1864.

favourably impressed that he expressed the opinion that they should form the subject of the Croonian Lecture of the Royal Society of London for 1860. His opinion having been endorsed by the Council of the Society, I was invited to discharge that onerous duty in April of that year. Having had no experience as a lecturer, and being only a third-year medical student, I undertook the task with grave misgiving. The lecture, however, passed off very satisfactorily, and evidently gave great satisfaction. I had prepared large transparent models of the ventricles of the heart, which showed how the two sets of spiral external fibres became continuous with the two sets of spiral internal fibres at the apex and the base, and how the spiral external and internal fibres formed external and internal layers which crossed each other. These models fairly captivated the audience ; the more especially as they were corroborated in every detail by the actual dissections which were on the table beside me. An abstract of my Croonian Lecture was published in the *Proceedings of the Royal Society* under date April 19, 1860.

At the end of the winter session 1859–60 Professor Goodsir gave out as the subject of his senior anatomy gold medal, " The Nerves and Ganglia of the Vertebrate Heart." The subject, however, was considered so difficult that no one competed for the much-coveted prize. In the summer and autumn of 1860 I had to prepare for the medical faculty an original thesis or inaugural dissertation on some scientific or professional subject with a view to graduate in medicine in 1861, and was induced to tackle the dissection of the nerves and ganglia of the heart ; a fresh hare was put up for me, and this more swift and cunning than the first. I selected as the title of my thesis, " The Ganglia and Nerves of the Heart and their Connection with the Cerebro-spinal and Sympathetic Systems in Mammalia." The preparation of the said thesis was, as I soon discovered, a very arduous task, as it necessitated my making a series of very difficult and delicate dissections. The dissections were carried on in a private room adjoining the Anatomical Museum, where I had frequent visits from Professor Goodsir. The interest which he took in the work as it progressed was quite remarkable. I made fifty-two nerve-dissections in all—namely, three large dissections of the calf, cat, and rabbit, showing the connection of the cardiac nerves with the cerebro-spinal and sympathetic systems of nerves, and forty-nine smaller dissections showing the distribution of the nerves and ganglia on the large vessels (the aorta and pulmonary artery) at the root of the heart, and the small vessels (the coronary sinus, anterior and posterior coronary arteries, &c.) on the surfaces and in the substance of the heart. I also prepared numerous microscopic specimens of the cardiac ganglia to show how the cardiac nerves were connected with the nerve-cells. The hearts dissected comprised those of man, the horse, calf, sheep, camel, panther, alpaca, and seal.

In this investigation, as in that of the muscular fibres of the ventricles of the heart, I had to devise a new mode of dissection. As every one knows, the sulci or grooves separating the different portions of the heart, if not the heart itself, are loaded with fat, and in this fat the nerves, in some cases as fine as silk threads, are for the most part lodged. It was of no use attempting to remove the fat by the ordinary methods of dissection ; it stuck to the scalpel, and in trying to get rid of it the nerves were displaced, stretched, and, in many cases, cut. I therefore fell back on my hot-water process, but in a modified form. The nerves of the heart were much too delicate to admit of boiling ; I consequently employed hot water, a little below the boiling-point, and with remarkably good results.

As the cardiac nerves were also too fine to bear handling or rough treatment of any kind I constructed an oblong metal trough to contain the hot water. This was provided with broad, flat ledges to support my arms and hands when dissecting ; the troughs had at either end an arrangement for receiving a revolving spindle which could be elevated and depressed at pleasure. The heart to be dissected was transfixed by the spindle which ran through one of the openings of the left auricle and the apex of the left ventricle. The spindle, with the heart fixed on it as explained, could be placed in any convenient part of the trough and elevated or lowered and rotated at will. I was thus enabled to work at the nerves on any part of the surface of the heart without handling the viscus —a matter of very considerable importance where everything was so fragile. When everything was ready and the spindle and heart were in position the trough was filled with nearly boiling water, the water being allowed to rise half an inch or so above the surface of the heart, the nerves of which were dissected under the hot water. The nerves were not dissected in the ordinary way with forceps and scalpel or with forceps and scissors. This would have resulted in the stretching, displacing, breaking, and cutting of the nerves. I therefore took an old nerve scalpel and blunted its cutting edge and point, and employed it as a needle for teasing out the fat, cellular tissue, &c., in which the nerves were imbedded. The fat, being partially melted by the hot water, was in the best possible condition for being teased out and, when so treated, it floated away. I never employed a knife, and very rarely scissors. By these means I was enabled to dissect the most delicate cardiac nerves *in situ*. They were in no case dragged or displaced. The hot water, moreover, always kept them taut and as they appeared prior to dissection.

[I here append photographs, taken by myself, of some of my nerve dissections (Figs. 1 to 7). They are fully described at pp. 573, 574, and 575 (Figs. 215 to 219 inclusive), in the body of the present work.]

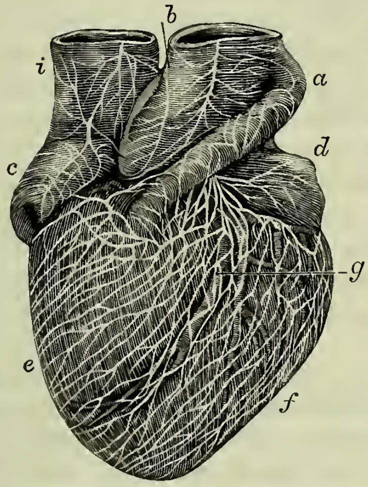


FIG. 1.

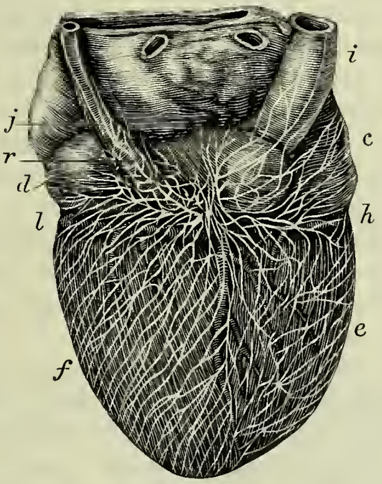


FIG. 2.

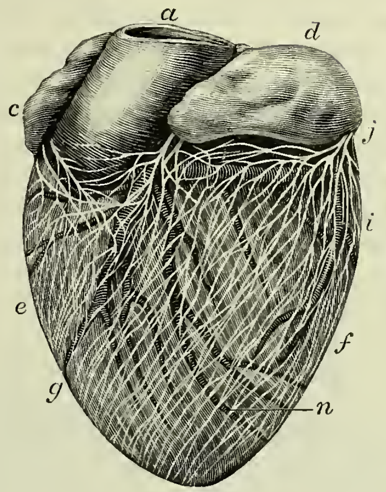


FIG. 3.

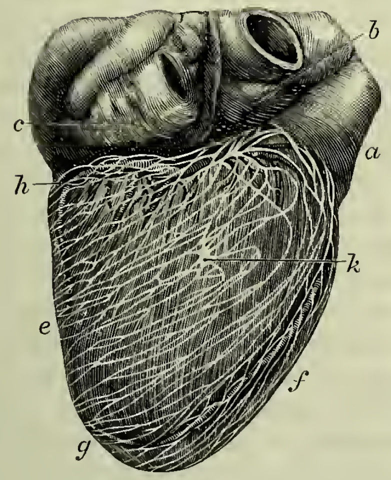


FIG. 4.

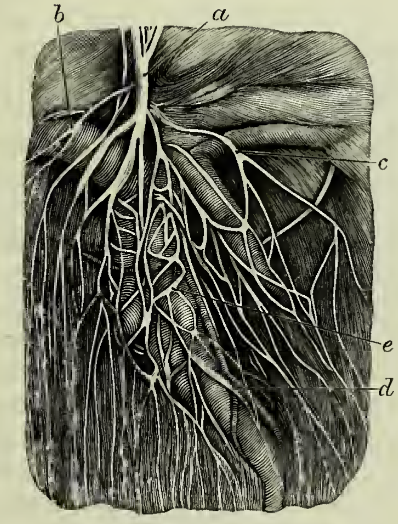


FIG. 5.

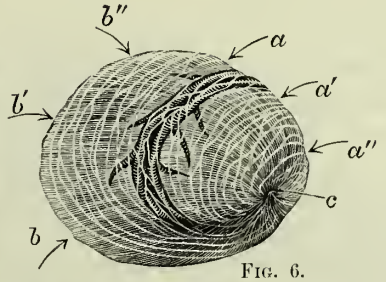


FIG. 6.

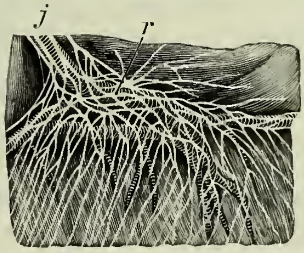


FIG. 7.

The hot-water method of dissecting was, in warm weather, very oppressive and severe on the eyes, but very satisfactory. The more heat and light, the better the result. It had only one drawback : the hearts, if not worked off in three or four days at most, were apt to become soft and to putrefy. This tendency to decay involved continuous work and a great strain while dissecting, so much so that, looking back, I am inclined to believe that the hot-water nerve-dissections were the most troublesome and difficult I have ever executed. When the hearts which were dissected under hot water were freed from fat, cellular tissue, &c., and the nerves were carefully dissected out, I boiled them, in some cases, in sulphuric ether—an expensive and ticklish process—resulting, in my case, in two rather serious explosions. The hot ether dissolved any tiny particles of fat which had escaped the hot water and my improvised blunted teasing scalpel. The nerve-dissections of the heart prepared in this way presented such a clean, smooth surface that in some cases they appeared more or less polished. One great advantage of the process was the non-stretching and the keeping of the nerves in exactly their original positions ; the hot water, as explained, preventing the nerves from becoming lax. Care had to be exercised as to the temperature of the water employed ; if too hot it shrivelled the nerves, if too cold the fat was not melted and could not be teased out.

As it was necessary in certain cases to distinguish the nerves from the finer blood-vessels, capillaries, and lymphatics, I resorted in not a few instances to injecting the cardiac blood-vessels. I explained to Mr. Stirling, who worked in an adjoining room, that I would require to employ an injection which could be forced into the

blood-vessels in the cold state and which would stand the heat and not shrivel on cooling. He at once suggested a cold injection of flour-and-water coloured with vermilion for the arteries and ultramarine blue for the veins. The idea was to make a stiff paste within the vessels by means of the hot water. This homely injection suited my purpose admirably, and nearly all of my injected nerve-dissections of the heart were so treated.

The nerves of the heart, as already indicated, were much more difficult to dissect than the muscular fibres of the ventricles. They were gossamer in texture, and the slightest slip of even the blunted scalpel made havoc. It was a case of constant watching, and the strain on head, eyes, and hand was very trying. I worked at the nerve-dissections from 8 A.M. to 6 P.M. each day for a whole summer and autumn, with an interval of an hour for luncheon. Nine hours' continuous work in and over hot water and in the heat and glare of the summer and autumn was, to say the least, not a little fatiguing. Experience, however, taught me that it was necessary to finish the nerve-dissections with all possible despatch. There was, as stated, a danger of their softening and even decomposing, if the dissection was too long continued. The hot water and the heat of summer necessarily emphasised the danger. I was, however, between Scylla and Charybdis. A strong light and a strong heat were both necessary to enable me to accomplish the delicate work on which I was engaged.

The summer session of 1860 was one of the busiest of my life. I got up each morning at four o'clock, and in the early hours wrote an essay on the "Presumption of Survivorship," which secured for me the gold medal in the class of medical jurisprudence. This essay was published in the *British and Foreign Medico-Chirurgical Review* for January 1865. The nerve-dissections of the heart, as it turned out, were wholly successful, and, with my inaugural dissertation describing them, obtained for me in 1861, when I graduated in medicine, a thesis gold medal, the highest honour the University of Edinburgh confers. The dissertation, which was illustrated, and contained drawings of the nerves of the heart and of the microscopic appearances presented by the ganglia of the nerves, was deposited in the University of Edinburgh Library, where it may be consulted. The nerve-dissections themselves I presented to the Anatomical Museum of my *alma mater*, where they can be examined. I mounted them in glass jars with glass lids as I had done the muscular fibre preparations of the ventricles. The muscular fibre and nerve dissections of the heart presented by me to the Anatomical Museum of the University of Edinburgh number in all 164. I subsequently photographed the nerve-dissections as I had done the muscular fibre ones, and a short account of them appeared in the *Proceedings of the Royal Society of Edinburgh* for 1865. They were also described and figured in my lectures "On the Physiology of the Circulation in Plants, in the Lower Animals, and in Man," which were originally published in the *Edinburgh Medical Journal* during the years 1872 and 1873, and subsequently republished by Messrs. Macmillan in book form in England and America in 1874, with 150 illustrations on wood.

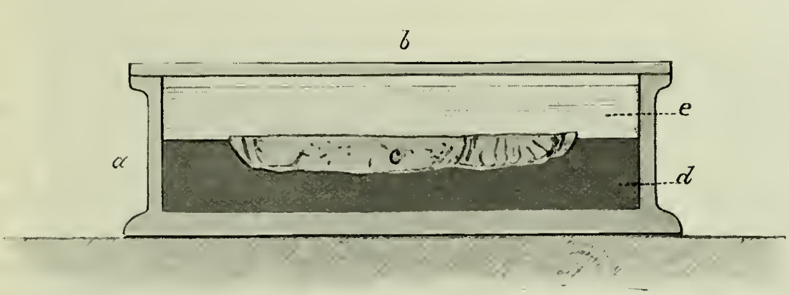
Towards the end of 1862 I was appointed first assistant in the Hunterian Museum of the Royal College of Surgeons of England, founded by the illustrious John Hunter, where Owen and Quekett had been conservators, and where Paget and Huxley often worked. The museum afforded endless opportunities for dissecting, injecting, making and mounting anatomical preparations of all kinds. It possessed vast stores of human and comparative anatomy stowed away in tanks, jars, bottles, &c., and fresh material was sent in quantity from all parts, especially from the Zoological Gardens in Regent's Park, and the various London hospitals. I found the higher dissection at the Hunterian Museum at a very low ebb. The museum could boast many magnificent specimens, the work of the famous John Hunter and others who followed him in bygone days, but fine modern preparations were conspicuous by their absence. As a matter of fact, no new high-class dissections or injections were being made, the authorities largely contenting themselves with remounting old specimens and keeping the collections in a state of efficiency. The art of making original dissections and injections had apparently been lost. There was, moreover, something like stagnation in the upper workrooms of the museum which I occupied, and where dissecting, injecting, and remounting were carried on.

I was allowed two assistants, Thomas and William Pearson (father and son). Old Tom the father was very gouty and somewhat frail, but a fine specimen of a frank, genial Englishman. His work consisted in remounting specimens and attending to store preparations. William, the son, waited upon me and performed minor offices in my department. He was a well-grown, good-natured lad, eighteen or twenty years of age, with a plain education and no knowledge either of anatomy or dissecting or preparation-making. I found him useful and faithful, and, as he took an intelligent interest in my work, I was delighted to teach him everything. He was very painstaking, and ultimately became a first-rate dissector. I give these details as he is the only individual living who knows and has practised my peculiar modes of dissecting, injecting, and preparation-making. This he has done for over thirty years with great advantage to the museum and profit to himself.

There were at the Hunterian Museum three workrooms in all, situated at the top of the building. These rooms were, when I entered on my duties, in a most insanitary condition. They were crowded with large and small jars and bottles containing vegetable and animal specimens of every conceivable kind. As the lids and

stoppers of many of them were imperfect, and the spirit in which the specimens were immersed had evaporated, the contents in many cases were semi-putrid and evil-smelling to a degree. As a consequence the atmosphere was laden with foul spirit and decomposing vegetable and animal matter sufficient to engender a plague. I at once set about sweeping out the Augean stables, and had all the jars and bottles overhauled, useless specimens thrown away, and fresh spirit added to such as were to be kept. The jars and bottles were also carefully stoppered. The amount of soiled spirit liberated during my cleansing operations, which under ordinary circumstance would have been thrown away, was sufficient almost to float a Spanish galleon. In order to prevent what would have been culpable waste I had a small rectifying still erected, similar to that employed in the anatomical department of the University of Edinburgh. Prior to my arrival all old and foul spirit was destroyed. The spirit employed in putting up preparations of every kind, even new preparations, was diluted methylated spirit with a distinctly yellowish tinge. Pure white, limpid, re-distilled spirit was unknown to Mr. W. H. Flower, the conservator, and to the museum authorities.

With a view to protect myself from the unsavoury, unwholesome atmosphere of the upper workrooms I invariably worked at an open window, preferring occasional colds to possible blood-poisoning. William Pearson was always at my elbow, as I required him constantly for holding, tying, cutting, cleaning instruments, attending to syringes, preparing injections, hot water, &c. I had always a kettle with boiling water on the fire in winter and a saucepan with boiling water on a Bunsen burner in summer. Boiling or very hot water was my sheet-anchor in every kind of dissection. My dissections were generally made in cold water. They were, however, invariably finished by the aid of hot water in a manner to be presently explained. I made hot and cold injections, but greatly preferred the latter worked up and finished in hot water, as they did not shrink on cooling, and always looked plump and fresh. I employed gelatin variously coloured for my hot injections, and white of egg, farina of various kinds, and plaster-of-Paris for my cold injections. The plaster-of-Paris injections, which were my invention, were especially successful. They took the most brilliant colours, did not shrink, and could be worked up in cold or hot water as desired. They, moreover, could be indefinitely preserved in spirit, which they did not in the least discolour.



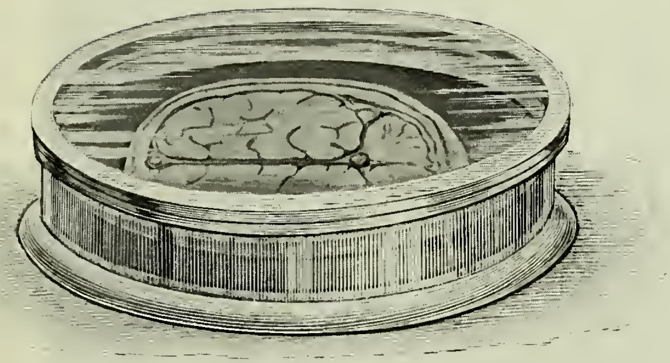


FIG. 8.—A. Section of a large round flat capsule or jar. *a*, Side of capsule ; *b*, glass lid of capsule ; *c*, dissection imbedded in plaster-of-Paris (*d*) ; *e*, clear spirit.
B. The capsule or jar as seen from above and before. Shows a section of a human brain imbedded in the plaster-of-Paris and covered with spirit. (Drawn by C. Berjeau for the Author.)

During my first year at the Hunterian Museum (1863) I devoted a considerable amount of time to devising and perfecting new modes of dissecting, injecting, and preparation-making and mounting. In this year I introduced the following novelties in museum-work in London : (1) the re-distillation and purification of foul spirit as carried on at the Anatomical Museum of the University of Edinburgh ; (2) a new form of preparation-jar with flat ground top and glass cover as devised by Professor John Goodsir ; (3) my hot-water methods of dissecting employed by me in Edinburgh in 1858, 1859, and 1860 ; (4) my mode of injecting blood-vessels with liquid plaster-of-Paris coloured red for the arteries, and blue for the veins ; (5) my method of distending the hollow viscera (heart, stomach, intestine, bladder, and uterus) and cavities generally with liquid plaster-of-Paris variously coloured ; (6) my plan of mounting dissections for teaching, examination, and museum purposes in liquid plaster-of-Paris run into the bottoms of large flat jars, capsules, and troughs, containing spirit and covered with glass lids (as the plaster-of-Paris was coloured with ultramarine blue the dissections were thrown out in relief, the effect being highly artistic) ; and (7) my mode of dividing the human body into sections by the aid of a very thin, finely toothed saw. By this means I obtained beautiful lateral, antero-posterior, and transverse sections of the head and neck,

the brain and soft parts being supported by the bones, cartilages, and hard parts. I also got fine sections of the human foot and other parts.[1]

[I annex drawings and photographs of: (*a*) my large flat jars with ground rims and transparent glass tops containing a dissection imbedded in plaster-of-Paris and covered with spirit; (*b*) an antero-posterior section of the human head and neck showing the brain and soft parts *in situ*; (*c*) a longitudinal section of the hard and soft parts of the human foot; and (*d*) a plaster-of-Paris cast of the ventricles of the human heart (Figs. 8 to 11).]

At the end of my first year in the Hunterian Museum an exhibition of the specimens (anatomical, physiological, and pathological) prepared during the year was held in the theatre of the Royal College of Surgeons of England. It was open to the scientific and professional public. Every one seemed pleased with the quantity and quality of the work done. It was a novelty in London to see highly finished dissections mounted in pure, colourless spirit in crystal jars with glass lids which admitted a flood of light. Similar annual exhibitions were held each year while I was in office. At these exhibitions anatomists, physiologists, physicians, surgeons, and other distinguished men were frequently present, and in this and other ways I was privileged to make the acquaintance of nearly all the leading medical and scientific men in London and the provinces—Sir William Lawrence, Sir William Ferguson, Sir James Paget, Sir George Burrows, Sir Thomas Watson, Professor Owen, Professor Huxley, Professor Sharpey, Professor Humphry, Professor Rolleston, Charles Darwin, Lockhart Clarke, Sir Andrew Clark, Sir Richard Quain, Dr. W. B. Carpenter, Sir John Lubbock, Dr. St. George Mivart, Dr. Edward Gray, Dr. Albert Günther, Dr. James Murie, Sir B. W. Richardson, Sir T. Spencer Wells, Dr. John Rae, Sir William S. Savory, Mr. Wheelhouse, Sir Samuel Wilks, and others.

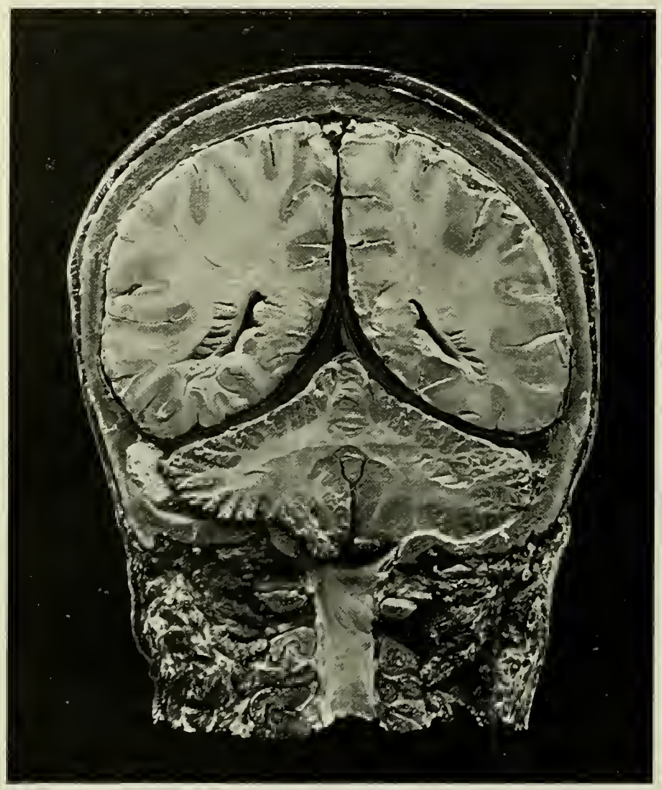


FIG. 9.—Photograph of an antero-posterior section of a human head and neck with the hard and soft parts *in situ*. Shows the right and left cerebral lobes, cerebellum, and the track for the spinal cord. When the section was made the hard and soft parts were in apposition. The brain has unfortunately shrivelled owing to the action of the spirit.

As is well known, the Royal College of Surgeons of England, in addition to being the proprietors and custodians of the Hunterian Museum, are also a great examining body. During my term of office at the museum the examinations for Membership of the College were held in the theatre of the College adjoining the museum, but all under the one roof. At certain periods of the year a number of medical students from the several London hospitals called "prosectors" came to the College to dissect bodies for the examinations. The dissections in some cases were none of the best, and as fresh dissections had to be made for every examination it occurred to me that much time and labour would be saved if I supplied the Court of Examiners with a set of carefully prepared, permanent examination specimens. I carried out my intention as follows. I procured a number of large, flat glass jars and earthenware troughs of various shapes, having a diameter of from twelve to eighteen inches. The upper edges or rims of these were ground flat to receive glass lids which could, if required, be hermetically sealed. When the dissections, prepared according to the hot-water method, were made I ran coloured liquid plaster-of-Paris (preferably dark blue) into the bottoms of the jars, and placed the dissections in the plaster-of-Paris before it set. The result was artistic to a degree. The coloured plaster-of-Paris contrasted finely with the pale dissections and made them stand boldly out. I injected the blood-vessels also with coloured liquid plaster-of-Paris—the arteries red, the veins blue. The specimens prepared in this way consisted of:—1. Sections which I made with a thin,

[1] The following is taken from the Annual Report of the Conservator (Mr. W. H. Flower) to the Museum Committee of date Jan. 6, 1864. It deals with work done in 1863. "The only other point to which the conservator feels it necessary to call the attention of the committee is the work performed by Dr. Pettigrew during the year. Of this only a portion is seen in the new preparations in spirit, physiological and pathological, now exhibited. Much time of his first year has necessarily been expended in arranging the workrooms, the condition of which, both as to cleanliness and general convenience, has been greatly improved. A considerable number of experiments have also been made as to the best materials for injecting blood-vessels and the method of displaying hollow viscera, the successful result of which quite justifies the expenditure of time they have occasioned. Preparations for the anatomical examinations for the Diploma of the College have also taken up much time; and many specimens which are partially dissected, not being quite ready for exhibition, will fall into next year's series of additions."

fine-toothed saw of the head and neck—vertical, antero-posterior, and lateral, also horizontal or transverse—at intervals of an inch or so, showing the nares, cavity of the mouth, fauces, pharynx, vocal chords, brain, and skull, *in situ*. Similar sections (antero-posterior views of the brain, skull, and soft parts) were put up permanently in glass jars in Room V. of the museum. 2. Sections of the foot—bones and soft parts. 3. Dissections of the viscera. 4. Dissections of the muscles, blood-vessels, and nerves of various regions. 5. Dissections of glands, ligaments, tendons, &c. These examination specimens, prepared and mounted permanently as described, were humorously designated "pickles" by the students, and I fear gave badly prepared men some trouble. They have now, I am glad to find, come into general use in the various teaching and examining institutions in this and other countries. So highly pleased was the Court of Examiners with the so-called "pickles" that the President of the College, Mr. John Hilton, was instructed to offer me an honorarium for the extra labour involved and as an acknowledgment of the new method. This I respectfully declined.

FIG. 10.—Photograph of a longitudinal section of the human foot (young individual), showing the hard and soft parts *in situ*—preserved in spirits in flattened jar with glass top. Displays the beautiful longitudinal arch made by the bones of the foot, and the soft fatty pads on the under surface of the foot at the heel and ball of the foot which cushion it so effectually in walking and running.

As my hot-water method of dissecting the muscles and tissues generally has never been described or published, the following short account may prove interesting and welcome. Supposing a human forearm was to be dissected, the following was the mode of procedure. I first carefully dissected the part with a scalpel and forceps in the ordinary way as I would a dissecting-room specimen. I then placed the part in a trough of cold water and re-dissected it under water with forceps and scissors, chiefly the latter. The re-dissection under water was a tedious process, and required much care and patience, the amount of fat, cellular, and other tissue to be removed being quite extraordinary. This done, I raised the dissection to the surface of the cold water and poured over its several parts in succession, from a wide-mouthed jug, hot water just off the boil. The result was the immediate shrinkage and permanent disappearance of all fat, cellular and other tissue, fluff, &c., which had escaped the scissors and which so greatly disfigure ordinary dissections when placed in fluids. Dissections made by the hot-water method present a smooth, almost polished surface. Great care and skill were required in applying the hot water. If the water was too hot or too long applied the part of the dissection which was being dealt with was made to contract too much. This catastrophe was avoided by suddenly dipping the part of the dissection under treatment in the cold water, which corrected the mischief. A moderate application of the hot water effectually got rid of the cellular tissue and fat of muscle, but a larger quantity was required in dealing with blood-vessels, fasciæ, tendons, ligaments, and bones. In the case of muscle the hot water was applied until the cellular tissue disappeared and the muscles were sufficiently shrunk to present a normal appearance.

FIG. 11.—Photograph of a plaster-of-Paris cast of the right and left ventricles of the human heart. Shows how the cavity of the right ventricle (*a*) curves and plaits spirally into that of the left ventricle (*b*) at the apex of the heart. This cast reproduces the exact shape assumed by the blood prior to its being forced out of the ventricles during the closure or contraction of the right and left ventricular walls.

In the case of blood-vessels it was applied until the cellular and fibrous structures presented a compact, even surface. In the case of nerves (the nerves of the heart, which, as explained, required special treatment, excepted) it was applied sparingly, and only until the strands of nerve-fibres were brought into relief. In the case of glands the dissector had to use his discretion. By a judicious use of hot water all the tissues of the body can be perfectly cleaned and rendered more or less taut relatively to each other. In this way the flaccid, dragged appearance presented by ordinary dissections is avoided. When every part of the specimen had been carefully subjected to the hot-water treatment the dissection was placed in a trough of weak spirit and dissected a third time. The third dissection in weak spirit was final, and not usually a serious business. The specimen was then suspended by silk threads in a crystal jar containing rectified spirit and hermetically sealed, preferably by the aid of a glass

lid fixed with gelatin dissolved in acetic acid. Dissections made by me according to the hot-water method some thirty-seven years ago are as good to-day as when first put up. They will, I believe, practically last for ever if kept supplied with spirit of the requisite strength. All such preparations require to have fresh spirit added occasionally—to make good the deficit caused by slow evaporation.

The plaster-of-Paris injections were made as under. Nozzles or short end tubes adapted to the point of the syringe to be employed in injecting were fixed in the blood-vessels, hearts, hollow viscera, &c., the whole being immersed in cold water in a deep basin by themselves. A handful or more of the finest plaster-of-Paris procurable was then dropped into two separate basins, each of which contained a given quantity of cold water, the water in the one case being coloured with vermilion, and in the other with ultramarine blue. When the liquid plaster-of-Paris, coloured as explained, was of the consistency of cream it was gently drawn into the interior of the syringe to prevent the ingress of air. The point of the syringe, charged with liquid plaster-of-Paris minus air, was then inserted into the nozzles fixed in the blood-vessels and structures to be injected, and the contents were slowly driven home. This form of injection must be done expeditiously, as a period arrives when the plaster-of-Paris sets very quickly and refuses to flow. Plaster-of-Paris when once set is not disintegrated by the action of spirit, neither does it shrink nor appreciably diminish in volume when exposed to spirit or hot water. It, moreover, gives off no colour, which is important. It is advisable when making plaster-of-Paris injections to clean out the nozzles, syringes, and basins at once with cold water. If this precaution be not taken endless trouble follows, it being next to impossible to remove the plaster-of-Paris when once set.

The more I employed the hot-water method of dissection and the cold mode of injection with liquid plaster-of-Paris, the more I was convinced of their value for teaching, examination, and museum purposes. In the old days specimens to be injected were slowly heated up in warm water and hot injections of various kinds gently forced into the blood-vessels, the specimens being dissected in cold water or in cold diluted spirit. As everything contracts on cooling the specimens prepared in this way looked withered and shrivelled when finished, a state of matters not improved by preserving them in spirit, which increases the shrinkage. According to the hot-water method introduced by me all these defects are avoided. In the new method the specimens in the first instance are placed in cold water and are injected with cold material—farina, flour, white of egg, or plaster-of-Paris. They are then dissected in cold water, hot water a little below the boiling-point being applied to them as the dissection proceeds. Specimens prepared by the new method do not shrivel when placed permanently in spirit; on the contrary, they present a fresh, full, blooming appearance. It should be stated that in the hot-water process the heat employed in finishing the specimens causes sufficient shrinkage to prevent further shrivelling when the specimens are finally placed in spirit for permanent preservation. The shrinkage obtained by the hot-water process is of the utmost importance, as it enables the dissector to contract and tighten tissues of all kinds which may have been dragged out and rendered flaccid during the process of dissection. By continually raising the temperature of the hot water a flaccid muscle can be made to assume the shape and position natural to it in a state of contraction or semi-contraction. This explains the taut condition of the tissues in my dissections of all parts of the human body and of the lower animals, especially their muscular arrangements.

The hot-water method of dissecting and making anatomical preparations, coupled with the cold plaster-of-Paris injections of blood-vessels, hollow viscera, &c., and the mounting of dissections in liquid plaster-of-Paris placed in the bottoms of flat glass jars, capsules, and earthenware and other troughs containing spirit and covered with glass lids, practically revolutionised the art of preparation-making, and introduced not only an element of stability, but also a distinctly artistic element. My methods were available equally for the largest and smallest specimens, and results not hitherto dreamt of were attained. It was possible to inject, to dissect, and to preserve a hip and thigh, a leg, an arm, or any large portion of the human body, or of the bodies of animals. Characteristic and outstanding specimens of human muscular dissections made by me by the hot-water method are to be seen in Room I. of the Hunterian Museum of the Royal College of Surgeons of England. Reference should also be made to the muscular fibre dissections of the stomach, bladder, and uterus, to be described presently. As examples of cold injections with plaster-of-Paris the series of preparations illustrating the movements of the valves of the vascular system in vertebrates should be mentioned. In this series the blood-vessels and the cavities of the auricles and ventricles of the heart are injected with liquid plaster-of-Paris coloured red and blue. Mixed dissections, that is, dissections displaying muscles, blood-vessels, nerves, &c., are to be found in the comparative anatomy series. Examples of ordinary vermilion and other injections by me also occur in this series. The human and comparative physiological series of dissections and injections between the years 1863 and 1868 were all made according to my methods, either by myself or by my assistant, William Pearson, under my immediate supervision. The cold injections and hot-water dissections were greatly admired by American visitors, and I had a tempting offer to cross the Atlantic and to commence operations on the other side. This offer I did not accept, from patriotic and other considerations.

In the years 1863 and 1864 I planned and commenced an elaborate series of dissections and injections of the human body, and of the bodies of the lower animals, on the hot-water and plaster-of-Paris methods. As a first instalment I took up the hollow viscera—namely, the heart, bladder, stomach, intestine, and uterus in man and animals. These I injected and distended with coloured liquid plaster-of-Paris. I then dissected the blood-vessels, nerves, and muscular fibres of each by the hot-water process. I also, as already indicated, devised, and in large measure executed, a series of carefully finished hot-water and plaster-of-Paris dissections and injections for examination purposes, the dissections being placed in liquid plaster-of-Paris run into the bottoms of large flat glass jars, capsules, and troughs filled with spirit and covered with glass lids. The various sets of dissections here referred to were all in hand at the same time, and were advanced by stages as suitable material came to the museum and was available. I worked at these continuously from 1863 to 1868, when I resigned my appointment at the museum from failing health.

In addition to what I called the physiological series, a large number of pathological specimens were dissected and prepared on the hot-water system mainly by my assistant, William Pearson. During the years 1863 and 1864 I made an extensive series of plaster-of-Paris injections and casts of the blood-vessels (arteries and veins), and of the several compartments of the heart, my object being to show how the valves of the blood-vessels and of the heart acted. I set the valves in motion by the liquid plaster-of-Paris, and when it set I could remove the walls of the blood-vessels or the walls of the auricles and ventricles in such a way as to display the valves in every possible position. The plaster-of-Paris injections gave exact casts of the blood-vessels, whether arteries or veins, and of the several compartments of the heart, and also of the valves and sinuses or pouches behind the valves. Further, they fixed the valves of the heart, arteries, and veins in various and perfectly natural positions. Lastly, they gave the precise forms assumed by the blood and the valves at every stage of the diastole and systole of the heart. They conclusively proved that the blood takes a spiral form within, and is spirally ejected from, the ventricles during the systole, and that the semilunar and auriculo-ventricular valves are spirally opened and spirally closed. A result so novel could scarcely have been foreseen. The proof obtained by the liquid plaster-of-Paris methods cannot, however, be gainsaid. The vascular series of dissections and plaster-of-Paris injections and casts are thirty-two in number, and form part of the permanent collection of the museum. They were considered worthy of separate descriptions in the museum catalogue. The results of this research, which entailed an examination of the entire valvular arrangements in the fish, the reptile, the bird, and the mammal, were communicated on March 21, 1864, in the form of a memoir to the Royal Society of Edinburgh, and published in the *Transactions* of that Society with two plates (fifty-seven figures), the same year. The title chosen for the memoir was "The Relations, Structure, and Functions of the Valves of the Vascular System in Vertebrata." As I was most anxious to give faithful representations of the movements of the cardiac and other valves and of the varying shape assumed by the blood during the diastole and systole of the heart, I took photographs of my vascular preparations on the roof of the museum. These I developed in a small, improvised dark room under considerable difficulties.

Fig. 12.—Photograph of a section of the base of the heart showing the segments of the aortic and pulmonic valves closed, wedged, and screwed into each other by means of liquid plaster-of-Paris made to flow into the aorta and pulmonary artery from above when the heart was placed on its apex. The mitral and tricuspid valves with their musculi papillares are in a state of inaction; the right auriculo-ventricular orifice being open as in diastole. Dissection permanently preserved in a glass jar in pure spirit with hermetically scaled glass lid.

[Specimen photographs of the blood-vessels and heart as distended with coloured plaster-of-Paris, and of the structure and movements of the valves of the veins, arteries, and heart are given at Plate xcix. of the present work, which see.

I also append a photograph (Fig. 12) of the base of the heart as preserved in spirit in its glass jar with the aortic and pulmonic valves in action.]

The results obtained by photography were so satisfactory that I urged the College authorities to construct a proper photographic studio and dark room on the leads for museum purposes generally. The subject was considered, but nothing came of it. Progress is proverbially slow. It was not until the year of grace 1888 that a fitting photographic studio was erected. In that year a storey was added to the museum, and the claims of photography were duly recognised. Nothing daunted, I continued my photographic operations on the roof in the clear morning light. I photographed in succession my dissections of the muscular fibres of the bladder and of the stomach and uterus. The bladder dissections, forty-five in number, were finished in 1865, and a memoir based on them was communicated to the Royal Society on June 21, 1866. It was published in the *Philosophical Transactions of the Royal Society* in 1867 with three plates (fifty-six figures), under the title, "The Muscular Arrangements of the Bladder and Prostate and the Manner in which the Ureters and Urethra are Closed." The bladders dissected included those of man and the lower animals ; they are permanently preserved and catalogued in the Hunterian Museum.

[Photographs of the bladder dissections are to be seen at Plates c. and ci. of the present work.]

The bladder dissections were made as follows. I fixed an injecting nozzle or end tube in the neck of the bladder, and placed both in a deep basin of cold water. I then added a handful or more of the finest plaster-of-Paris to a given quantity of cold water in a second basin, the water being deeply coloured with ultramarine blue. When the coloured cold water and plaster-of-Paris were thoroughly mixed by stirring with the hand, and were of the consistence of thick cream, I slowly filled the injecting syringe to prevent the admission of air into it and cautiously distended the viscus, taking care to move it about between the hands in the cold water, in order to preserve its shape while the plaster was setting. The degree of distension could be regulated at discretion. As the deep blue plaster-of-Paris shone through the thin walls of the bladder, the muscular fibres, nerves, and blood-vessels were thrown into bold relief, and could be traced and dissected without difficulty by the aid of hot water. This plan had the great merit of putting everything on the stretch, and so securing the relative position of the muscular fibres, nerves, and blood-vessels to each other. The arrangement lent itself admirably to the hot-water process of dissection.

The dissections of the stomach were made in precisely the same way, with the following slight difference (in some cases) for human stomachs. The walls of the human stomach being in some instances exceedingly thin—so thin, in fact, as only to furnish continuous layers in certain parts—the stomachs were artificially shrunk before being distended with liquid plaster-of-Paris. The shrinkage was effected as under : the pyloric end of the stomach was tied off, and the injecting nozzle fixed in the œsophageal or cardiac end of the stomach. A small quantity of nearly boiling water was then injected into the stomach, and the stomach was sunk in a trough of very hot water. The walls of the stomach, being bathed by hot water on either side, shrunk to the desired dimensions. The water in the interior of the stomach was then withdrawn, and cold, liquid, coloured plaster-of-Paris was made to take its place. The human stomachs so prepared were dissected by the aid of hot water, as in other cases. The stomach dissections, seventeen in number, included those of man, the monkey, horse, bear, cat, dog, sheep, and porpoise, and form part of the permanent collection of the museum. They were made the subject of a memoir communicated to the Royal Society in June 1867, with two plates (twenty-four figures), an abstract of the memoir appearing in the *Proceedings of the Royal Society* for June 20, 1867, under the title, "On the Distribution of the Fibres in the Muscular Tunics of the Stomach in Man and other Mammalia."

[Photographs and drawings of the stomach dissections by myself occur at Plates cii. and ciii. of the present work.]

The dissections of the uterus, ten in number, were made in the same way as those of the bladder. The arrangement of the muscular fibres in the stomach, bladder, uterus, and heart closely resemble each other. They all form characteristic figure-of-8 loops, the loops being arranged in more or less perfect layers.

The dissections of the muscles (voluntary and involuntary), blood-vessels, nerves, &c., of the human body and of the bodies of animals were all made by my hot-water and plaster-of-Paris processes. These are now sufficiently numerous to fill a whole museum, and occupy a unique position in the annals of anatomy. Not only did I design this great series but, as already partly explained, I actually dissected and mounted in great specially-made glass jars, with glass lids, some of the largest and most important of them.[1]

[1] The following extracts bearing on this subject are from the annual reports published by the conservator of the museum, Mr. W. H. Flower :—

"*Physiological series.*—It only remains now to speak of the preparations preserved in spirits, added during the year, mostly prepared either by or under the immediate superintendence of Dr. Pettigrew, assistant in the museum. In number these considerably exceed those of the past year. They include a series illustrating the structure and action of the valves of the heart and of the blood-vessels. As the value of these most instructive and beautifully prepared specimens must be much enhanced by an account of the special points they are intended to illustrate, it has been thought desirable to append to this report a concise description of each of these preparations. Since their completion Dr. Pettigrew has been engaged in making a series of preparations demonstrating the arrangement of the muscular fibres of the urinary bladder (Report of date Dec. 31, 1864).

"*Physiological collection.*—The addition of specimens in spirit to this department, having chiefly in view the increase of preparations illustrating normal human anatomy, has mainly occupied Dr. Pettigrew's attention during the year (1865–66). Among those now shown to the

As illustrative examples of human muscular dissections made by me, during my term of office, by the hot-water method I would direct the attention of the reader to the following, contained in Room I. of the Hunterian Museum of the Royal College of Surgeons of England, and duly described in the museum "Catalogue of Dissections

FIG. 13.

FIG. 14.

FIG. 13.—Photograph of a dissection of the superficial muscles of the left scapula and upper arm. Shows shoulder and other muscles, especially the deltoid. The scapular muscles and those on the inside of the arm cannot be seen in the present photograph. The photograph is taken from dissection No. 29, deposited in Room I. of the Hunterian Museum and described in the official "Catalogue of Dissections and Models illustrating Normal Human Anatomy."

FIG. 14.—Photograph of a dissection of the superficial muscles of the left half of the pelvis, hip, and thigh. Shows hip and thigh muscles, especially those in the interior of the pelvis and on the anterior portion of the thigh. The gluteal or hip muscles proper, and those occurring on the posterior of the thigh, are not seen in the present photograph. They are, however, all carefully dissected. The photograph is taken from dissection No. 104, deposited in Room I. of the Hunterian Museum, and described in the official "Catalogue of Dissections and Models illustrating Normal Human Anatomy."

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committee is an extensive series of very highly finished preparations, exhibiting in an exhaustive manner the disposition of the muscular fibres of the human bladder. The results obtained in the dissection of these specimens have been described by Dr. Pettigrew in a paper read before the Royal Society on the 21st of last June. Besides these, a commencement has been made of a series of preparations showing in a permanent manner the voluntary muscles of the human body, to be followed, if the committee think it advisable, by others, which will afford a complete exposition in detail of every portion of the body. The amount of time and labour expended in the production of such preparations is very great; and as there are sometimes difficulties in obtaining suitable materials when required, the completion of such a series as is contemplated will occupy several years; but, if carried on as now commenced, this College will be able to show a museum of human anatomy unrivalled by that of any other collection in the world" (Report of date July 2, 1866).

"*Physiological collection.*—Dr. Pettigrew has also, as in previous years, made some instructive preparations illustrating human anatomy. These are quite irrespective of the large and beautiful series prepared expressly for the Court of Examiners" (Report of date July 1, 1867).

"*Physiological series.*—The old collection remains in the same condition as before. . . . In the meanwhile, additions are continually being made as opportunities occur. Many of those shown on the present occasion are the work of the late assistant in the museum, Dr. J. B. Pettigrew. This gentleman in January last resigned the office he had held for five years on account of an impairment of vision (it may be hoped, only temporary) occasioned by over-exerting his eyes in following out a series of minute researches. . . . I am glad to take this opportunity of acknowledging the numerous improvements in the methods of preparing and mounting anatomical specimens which Dr. Pettigrew introduced into the institution, and especially in originating a higher standard of excellence in finishing preparations in spirits than had been thought necessary before, and which I hope will never be departed from" (Report of date June 29, 1868).

and Models illustrating Normal Human Anatomy" :—No. 29 : superficial muscles of the left scapula and upper arm. (This is a large and illustrative dissection.) No. 34 : superficial muscles of the left forearm and hand. (This is one of the most finished muscular dissections in the museum.) No. 35 : deep muscles of the left forearm and hand. No. 40 : superficial muscles of the right hand. No. 43 : right-hand dorsal and plantar interossei. No. 104 : superficial muscles of the left half of pelvis, hip, and thigh. (This is the largest muscular preparation in the museum, and one of the most striking.) No. 112 : superficial muscles of the left leg and foot—a typical

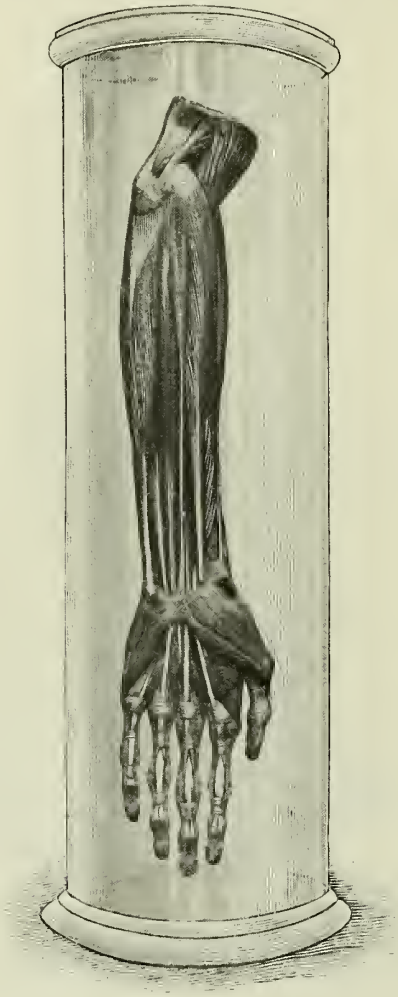

Fig. 15.

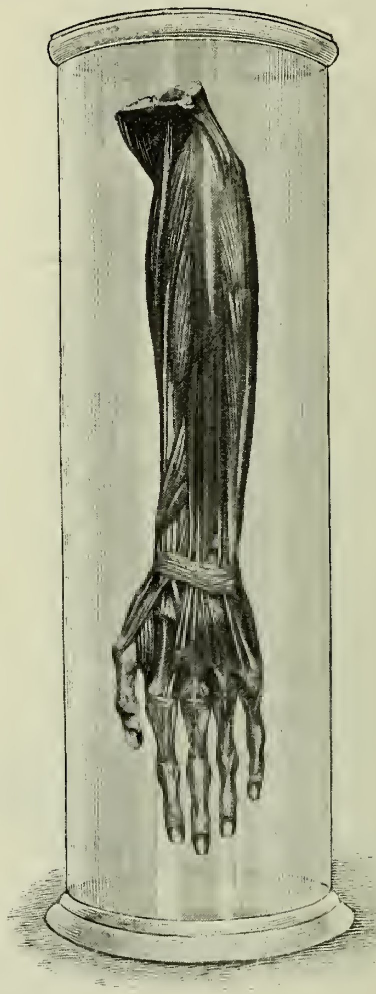

Fig. 16.

Fig. 15.—Photograph of a dissection of the superficial muscles of the left forearm as seen anteriorly (palmar aspect). This photograph is taken from dissection No. 34, deposited in Room I. of the Hunterian Museum and described in the official "Catalogue of Dissections and Models illustrating Normal Human Anatomy."

Fig. 16.—Photograph of the same dissection as seen posteriorly (dorsal aspect).

specimen. No. 113 : deep muscles of the right leg and foot. No. 118 : superficial muscles of the left foot. No. 119 : ditto second layer of muscles of the right foot. No. 121 : ditto third layer of muscles of the left foot. Nos. 181, 182, 274, 275, 276, 286, 287, and others of the catalogue were also dissected and prepared by me by the hot-water method.

[I subjoin original photographs (Figs. 13 to 20) of eight specimens of my hot-water dissections taken in their large, specially made jars ; the jars being filled with beautiful clear spirit. The jars have glass lids which flood the specimens with light. The lids are hermetically sealed with a view to the permanent preservation of the dissections. These preparations have not changed in the least for forty years. There will be no difficulty in identifying them with the originals deposited, as already explained, in Room I. of the Hunterian Museum of the Royal College of Surgeons of England (London).]

In addition to the dissections already referred to, and also forming part of the great museum series, though

separately catalogued and placed for convenience in Rooms IV. and V. of the Hunterian Museum, are my elaborate hot-water dissections, plaster-of-Paris injections, casts, &c., over 100 in number, as follows: (1) my dissections, plaster-of-Paris injections, casts, &c., of the heart, blood-vessels, and valves of the vascular system in vertebrata; (2) my dissections of the muscles, blood-vessels, and nerves of the bladder, prostate, &c.; (3) my dissections of the muscles and nerves of the uterus in the human female, the cow, mare, sheep, bitch, guinea-pig, &c.; (4) my dissections of the œsophagus, stomach, &c., in man and in the lower animals; and (5) my sections made with

Fig. 17.

Fig. 18.

Fig. 17.—Photograph of the same dissection as seen in a semi-pronated position.

Fig. 18.—Photograph of a dissection of the superficial muscles of the left leg and foot. Shows the muscles on the anterior and left lateral aspect of the limb. The photograph is taken from dissection No. 112, deposited in Room I. of the Hunterian Museum and described in the official "Catalogue of Dissections and Models illustrating Normal Human Anatomy."

a fine saw of the human foot and head, showing the scalp, skull, brain, and other parts *in situ*. These saw-cut sections, so far as I know, were the first of their kind. Some years later Braune of Leipsic sawed frozen human bodies in all directions and with remarkably good results. The practice has now become quite common. Latterly, plaster-of-Paris casts have been taken of the sections, and the several parts displayed coloured to imitate nature. These coloured plaster-of-Paris casts of the sections leave nothing to be desired for teaching and examination purposes, as the subjoined original photograph taken from one of them will amply testify (Fig. 21, p. 1381).

During the years 1866 and 1867 an unusually large number of pathological specimens were prepared and mounted for the museum. I found time, however, to add a considerable number of finished dissections to the great anatomical and physiological series. Amongst them I may mention (1) the deep muscles of the human forearm and hand; and (2) the deep muscles of the human leg. These two dissections prepared by the hot-water

method are to be seen in Room I. of the Hunterian Museum, and are numbered 35 and 113 in the "Catalogue of Dissections and Models illustrating Normal Human Anatomy."

Having from 1863, and previously to that date, taken a keen interest in, and made numerous dissections and experiments on, the subject of flight, I in 1866–67 injected the air-sacs and hollow bones of the swan and goose with liquid coloured plaster-of-Paris in order to ascertain what part, if any, the heated air contained in these cavities played in the production of flight. After carefully investigating the subject I came to the conclusion that the hollow bones and air-sacs had nothing whatever to do with flight, and for the following reasons: (1) bats and some of the fastest flying birds have neither hollow bones nor air-sacs; (2) birds which do not fly, such as the emu, have air-sacs; (3) air-sacs are found in animals never intended to fly (of these I may mention the air-sacs

FIG. 19.

FIG. 20.

FIG. 19.—Photograph of a dissection of the superficial muscles of the sole of the left foot as seen from beneath. The photograph is taken from dissection No. 118, deposited in Room I. of the Hunterian Museum and described in the official "Catalogue of Dissections and Models illustrating Normal Human Anatomy."

FIG. 20.—Photograph of a dissection of the second layer of muscles of the sole of the right foot as seen from beneath. The photograph is taken from dissection No. 119, deposited in Room I. of the Hunterian Museum and described in the official "Catalogue of Dissections and Models illustrating Normal Human Anatomy."

connected with the larynx of the orang-outang and the gular pouch of the bustard); and (4) the heated air imprisoned in the air-sacs of flying birds is so insignificant in quantity that it can exert no appreciable influence in elevating the bird.

In March 1867, I delivered a lecture "On the Various Modes of Flight in Relation to Aëronautics" at the Royal Institution of Great Britain, in which I pointed out that, contrary to all expectation, the wing of the insect, bat, and bird is a screw structurally and functionally, and that it strikes downwards and forwards during the down stroke, and not vertically downwards, or downwards and backwards, as was universally believed. I also demonstrated, in a memoir communicated by Professor Huxley to the Linnean Society in June 1867, that the wing forms a figure-of-8 track in space when the flying creature is artificially fixed, and that the figure-of-8 is opened out or unravelled, and describes a waved track, when the flying animal is advancing freely in space.[1] Professor E. J. Marey,

[1] "On the Various Modes of Flight in Relation to Aëronautics" (*Proceedings of the Royal Institution of Great Britain*, March 22, 1867). "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom" (*Transactions of the Linnean Society*, vol. xxvi., read June 6 and 20, 1867).

of the College of France, Paris, corroborated my views as to the figure-of-8 and waved movements made by the wing some two years after I announced the discovery.[1]

Later, Professor Marey says: "I have ascertained that in reality Mr. Pettigrew has been before me and represented in his memoirs the figure-of-8 track made by the wing of the insect, and that the optic method to which I had recourse is almost identical with his. But we differ entirely as to the interposition of the trajectory seen by us both. I hasten to satisfy this legitimate demand, and leave entirely to Mr. Pettigrew the priority over me relatively to the question as restricted."[2] Professor Marey in his admission of priority endeavours to make a distinction without a difference, for in another place, when speaking of the optic method by which the figure-of-8 was revealed to me, and subsequently to him, he writes: "We have seen, when treating of the mechanism of insect flight, that the fundamental experiment was that which revealed to us the figure-of-8 course of the point of the wing throughout each of its revolutions. Our knowledge of the mechanism of flight naturally flowed, if we may so say, from this first notion." As a matter of fact, the so-called restriction of Professor Marey consisted in an erroneous and inaccurate representation of my descriptions and drawings of the figure-of-8 and waved movements made by the wing published in the twenty-sixth volume of the *Transactions of the Linnean Society*, to which allusion has been made. Professor Marey also blundered as to the figure-of-8 spiral movements made in locomotion generally, and as to the screw configuration and function of the travelling organs of animals as a whole. It is easy to apply recording apparatus (the graphic method) to illustrate and to verify a principle once discovered and explained, and this is all that Professor Marey has done so far as the figure-of-8 and waved movements made by the wing are concerned. Mere mechanical corroboration, however, does not invalidate the original discovery, neither does it establish a claim to any part of the original discovery, as Professor Marey seems to think.

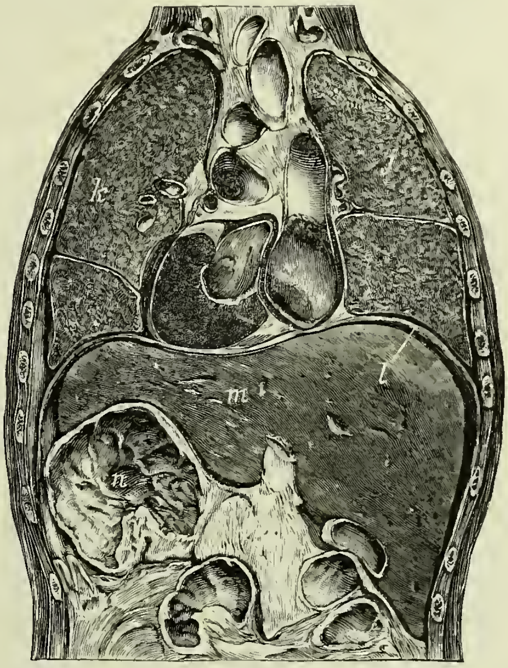

FIG. 21.—Photograph of a plaster-of-Paris cast of an antero-posterior section of the frozen human body with the viscera *in situ* as during life. Shows how admirably the viscera fill the cavities of the thorax and abdomen. In the centre of the thorax the heart and great vessels, &c., are seen. On either side (*j*, *k*) the lungs are observed. Separating the chest from the abdomen the thin partition known as the diaphragm (*l*) is met with; while beneath the diaphragm the liver (*m*), the greatest gland in the body, is found. The stomach (*n*) and the bowels occupy the space beneath the liver.

In the latter part of 1866 and the early part of 1867 there was, as indicated, a great pressure of work at the museum and also in making dissections and preparations in connection with the examinations of the Royal College of Surgeons of England, and in order to overtake it three medical students were temporarily employed. I showed them how to inject with liquid plaster-of-Paris and to mount dissections in coloured plaster-of-Paris run into the bottom of flat glass jars and troughs containing spirit and covered with glass tops, but I did not explain to them how to make hot-water dissections as practised by myself, and subsequently by my assistant, William Pearson. Mr. Moseley was the best of the temporary helps. He did some very good work, but his dissections presented a bleached, soft, sickly appearance from his having soaked them in acids. Two of his best specimens are to be seen in Room I. of the Hunterian Museum. They bear numbers 165 and 168 (nerves, &c., of face) in the museum "Catalogue of Dissections and Models illustrating Normal Human Anatomy." The following notice of the dissections prepared for the examinations of the College appeared in *The Lancet*:[3]—

"ANATOMICAL PREPARATIONS AT THE COLLEGE OF SURGEONS.

"Under the above heading in *The Lancet* of the 13th of October we gave an account of the preparations which have been specially dissected for examinational purposes at the College, and regret to find that we did scant justice to the original projector of the method of preserving these dissections—Dr. J. B. Pettigrew, the able assistant in the College museum. As our notice excited considerable attention among those members of the profession engaged in teaching anatomy, we may state that the preparations were begun by Dr. Pettigrew in 1863, and have been more or less in progress ever since; and that the assistance of the present prosector (Mr. Moseley) has only been

[1] *Revue des Cours Scientifiques de la France et de l'Étranger*, Feb. 13, 1869, and subsequently.
[2] *Comptes Rendus*, May 16, 1870, p. 1093.
[3] *The Lancet*, Dec. 8, 1866, p. 640.

called in during the last few months, owing to Dr. Pettigrew's other engagements. Those who have examined that gentleman's splendid dissections of the muscles preserved in the museum, and exhibited at the annual election last summer, will fully understand what an able and painstaking dissector is Dr. Pettigrew. The method of employing plaster-of-Paris to fill hollow viscera is well seen in the elaborate series of dissections of the human bladder made by Dr. Pettigrew, and now added to the Hunterian Museum; and his system of throwing dissections into relief by mounting them in coloured plaster, pursued in the preparations for examination, is well worthy of imitation. The best colouring-matter is found to be ultramarine, the beautiful blue of which forms a capital contrast to the partially whitened tissues. This is added to the water to be mixed with the plaster-of-Paris, which is made sufficiently thin to flow easily around the dissection placed in a shallow pan. The plaster sets almost immediately, and may be kept in spirit for any length of time without becoming discoloured. The edge of the pan having been previously ground, a plate of glass fits closely upon it, and prevents any but insignificant evaporation."

The following appeared in the *Medical Times and Gazette*:[1]—

"THE ANATOMICAL PREPARATIONS AT THE COLLEGE OF SURGEONS (LONDON).

"We had recently an opportunity of examining the dissections submitted to the candidates for the primary examination, and anything more beautiful and better calculated to test the accuracy of anatomical knowledge and teaching we have never seen. The recent specimens were very well and plainly got out; but what were formerly termed 'pickles' were masterpieces of workmanship—none of the miserable ancient preparations which we remember to have seen at one time, and which would take a conjuror to say what they were, far less a nervous examinee. The specimens are in many cases injected with very brilliant colours, and the nerves, tendons, fasciæ, &c., most carefully cleaned and whitened.

"Students seem to have a terrible bugbear in what is termed an 'out-of-the-way section,' or a 'window,' or a 'side view,' but these should be always, as far as possible, shown them by their teachers, or they should be taught more 'topographically,' so as to know and recognise any tissue or structure from whatever point of view shown them. It is not to be supposed that every section can be shown in the dissecting-room, but this might be done from time to time on a 'class subject.' The preparations to which we allude are set in moulds of plaster-of-Paris; these are sunk in flat pans and a sheet of glass over all. Indeed, the array of preparations we saw would, in our estimation, give a student courage rather than dismay him, from the plain and evident manner in which the different structures are displayed. The credit of these dissections is due to Dr. Pettigrew and Mr. Moseley."

It will be seen from the foregoing that as a matter of fact Mr. Moseley had no part either in the discovery of the liquid plaster-of-Paris method of injecting or in the mounting of the dissections in coloured liquid plaster-of-Paris run into the bottom of flat glass jars, containing spirit and covered with glass lids.

Towards the end of 1867, my eyesight becoming impaired and my health generally failing, I resolved to resign my appointment at the Hunterian Museum. The President and Council of the Royal College of Surgeons of England point-blank refused to let me go, and would not accept my resignation. They said, "We will give you a three or six months' holiday and keep your place open." I, however, felt that the continuous strain inseparable from my peculiar mode of dissection and the confinement of London were too much for me, and resigned unconditionally. The following sentence in *The Lancet*[2] chronicled the event:—

"The magnificent series of dissections with which Dr. Pettigrew has enriched the College of Surgeons has been more than once noticed in these columns, and our readers, whether professed anatomists or not, must regret the suspension of the priceless labours of the 'best dissector of the day,' as a well-known London teacher of anatomy termed him."

Before severing my five years' connection with the Hunterian Museum of the Royal College of Surgeons of England I wrote out a detailed account of all my hot-water and other methods of dissecting and preparation-making, my mode of injecting with liquid plaster-of-Paris and other cold materials, and my plan of mounting dissections in flat glass jars, troughs, capsules, &c., into which coloured liquid plaster-of-Paris had been run and which contained spirit and were covered with glass lids, my object being to place it in the hands of Mr. W. H. Flower, the curator, who was totally ignorant of my hot-water and other contrivances for making finished dissections. I intended the detailed account in question as an heirloom to my successors for their instruction and guidance in the difficult art of preparation-making in connection with the higher anatomy. My assistant, William Pearson, interposed with the words, "Oh, sir, if you please, don't do that; your so doing will not benefit you and will utterly ruin my prospects of preferment at the museum." This had not occurred to me, and, as Pearson had been

[1] *Medical Times and Gazette*, Jan. 26, 1867.

[2] *The Lancet*, Jan. 18, 1868, p. 97.

a good servant, I tore up the document without in the least desiring to conceal my methods then or subsequently. This happened some thirty-three years ago, and during the greater part of that long period William Pearson has been engaged in extending according to my methods the great series of human and comparative anatomy dissections, injections, casts, &c., which I designed, and a considerable number of which I executed. This superb collection of hot-water dissections, liquid plaster-of-Paris injections, casts, &c., are, for the most part, now fittingly housed by the Royal College of Surgeons of England in a large new museum, adjoining and opening into the original Hunterian Museum. The work done by William Pearson after I retired from the museum, and the position now occupied by him, in great measure justify my action in his favour ; still I have always had it on my mind to explain the situation for the sake of a future race of anatomists. William Pearson has now had ample innings, and the time has arrived when everything should be fully and fairly explained. I did not originally, neither do I now, attach much importance to my hot-water and other methods of dissecting, injecting, &c., although I am bound to admit that their discovery involved much close and consecutive thinking and planning, and a large number of experiments extending over several years.

The present communication on anatomical dissection, injection, and preparation-making as devised and practised by me at the University of Edinburgh and at the Hunterian Museum of the Royal College of Surgeons of England would assuredly never have been written but for the importunity of friends, among whom may be mentioned Mr. Thomas Bryant, late President of the College. These friends represented to me that the methods by which such splendid results had been achieved would be lost if I did not come to the rescue. They further urged that it was due to myself to explain the situation, especially as questions had been raised as to the real author of the great series of human and comparative anatomy dissections, casts, and injections referred to. I felt that there was force in the arguments employed, and as I had no wish to conceal anything by which the fascinating studies of anatomy and physiology could be advanced, I have given, as far as my recollection serves, an exact account of the circumstances under which the various forms of dissecting and injecting, making of casts, &c., practised by me were devised and carried out. The foregoing, I doubt not, will be duly endorsed by William Pearson, who still plies his avocation as dissector, injector, and preparation-maker at the Hunterian Museum of the Royal College of Surgeons of England.

Some time ago I had my attention drawn to a notice in the *British Medical Journal*[1] to which it may be well if, in conclusion, I direct attention. The notice is inaccurate and wholly misleading, as every one who reads this communication will readily perceive. In the notice referred to, and which I quote below, Sir William H. Flower is bracketed with me as having developed the talent of William Pearson as a dissector, which is, of course, absurd. He is further erroneously credited with having directed Pearson in the preparation of the great series of human and comparative anatomy dissections (muscles, ligaments, blood-vessels, and nerves), which series, as already explained, I not only designed, but a large number of which I actually dissected with my own hands, and every one of which has been dissected by my hot-water and other methods, these methods never having been known to Sir William Flower. I am also represented as a student inferentially learning my anatomy at the museum and the College, while in reality I was a duly qualified Doctor of Medicine of the University of Edinburgh before I went to London, and before I made the acquaintance of either the museum or the College. The misleading notice to which I refer, and to which I naturally take exception, is as follows :—

"Amongst the duly appointed students who were termed 'assistants in the museum,' was Professor Bell Pettigrew, the first dissector of modern high-class permanent anatomical preparations. His work, demonstrating the muscular apparatus of the heart, stomach, and bladder, stands in the museum as a monument. Flower and Pettigrew developed the talents of the prosector to the College, Mr. Pearson, a true artist in dissection. Under the conservator's directions he prepared the fine series of spirit preparations illustrating human and comparative anatomy which is so much admired by all visitors to the museum. The late Lord Tennyson, hardly an enthusiast about modern science, remarked, when paying a visit to the museum twenty years ago, that he had never imagined how so grim a subject as anatomy could be made so beautiful."

Since writing the foregoing, I have come across a letter from William Pearson addressed to me so far back as February 28, 1882. The letter speaks for itself, and I publish it exactly as in the original. In it he volunteers the following statements : (*a*) *that he is not the originator* of the series of dissections of muscles, ligaments, blood-vessels, and nerves made by him for the Museum of the Royal College of Surgeons of England ; (*b*) *that the dissections are made according to a new and unknown process ;* and (*c*) *that he has resolved not to communicate the secret* of the new process to his assistant lest, by so doing, he might impair his own prospects with the College of Surgeons authorities, from whom he hopes to get an increase of wage.

[1] *Brit. Med. Jour.* (Queen's Commemoration Number), June 19, 1897, p. 1592.

Royal College of Surgeons of England,
Lincoln's Inn Fields, London, W.C.
28th day of February 1882.

My dear Sir,—Many thanks for the Biography of your life which I had not seen before and I have read it through several times, and I think it very good. how it brings many happy days to one's memory things that are mentioned in it are being followed out as though you were in the upper work room now, viz. Cleanliness and fresh Air ? I have had new sashes and frames put in lately which admits of more light and gives better ventilation it surprises the people here that I do not catch cold as I keep the window open the same all the year round. and the rooms are as free from smell as days gone by. I thank you also for your kind mention of me in regard to the making of the specimens which I have increased to 19 specimens of ligaments 39 of muscular. 18 of vascular and 16 of nerves. exclusive of 5 ready to go into the Museum they form a fine series, and they are greatly used by Art students as well as Medical and they only want an inspection from the originator to complete the thing and I feel certain he will be pleased with his visit. You kindly mention my wife and father, the former with my little boy are quite well, My Father (I can hardly say sorry) died two weeks back. he was a great sufferer, he had gout all over him we could not wish him to live, so you can give an Idea the trouble I have had, loosing both parents so closely together.

I have got a very good assistant a youth from Cambridge he does not know much. he is to be taught the Art. *Is he?* I know the College too well for that. It will not do to have two Richmonds in the field. I completed my 25 year in their service last September and applied for an increase in my pay. I reminded Prof. Flower that the Work done could speak for itself and my character he well new, as I have not been once called to account and have not been once late. he said was it in his gift I should have an increase at once, he applied to the committee and they awarded me an increase of 10s. per week making my pay £2 weekly.

I am now busy dissecting a large ant Eater for Prof. Flower's lectures and as usual have got plenty to do.

the people at the College are very well and often mention you and hope you are well.

Please to excuse the hurried finish of this as I am wanted and hope you will continue well and prosprous is the wishes of your's most Faithfully,

W. PEARSON.

APPENDIX II

AËRIAL LOCOMOTION—PETTIGREW *versus* MAREY[1]

By PROFESSOR COUGHTRIE

The great interest taken in aërial locomotion, and the increasing belief in the feasibility of a flying machine, invest works on natural and artificial flight with a certain significance and importance which cannot be over-estimated in the present day, characterised as it is by unusual progress and invention.

The works to which we wish more especially to direct attention, and which have attracted an unusual share of notice, are those of Dr. J. Bell Pettigrew, of Edinburgh, and Professor E. J. Marey, of Paris.

The names of Dr. Pettigrew and Professor Marey are well known in the scientific world, and require only to be mentioned. Both gentlemen are physiologists of a high order, both have experimented largely on the subject under consideration, and both, as a consequence, are entitled to be heard.

The object of the present article is to show that these *savants*, notwithstanding certain apparent differences (and notwithstanding much that has been written to the contrary), essentially agree. The fundamental features of flight, according to both, are the same. If there be differences, they refer, for the most part, to time and the mode of treatment adopted, Dr. Pettigrew having published his views some two years before Professor Marey.

Dr. Pettigrew obtained his results by transfixing the abdomen of insects with a fine needle, and watching the wings vibrate against a dark background; by causing dragon-flies, butterflies, blowflies, wasps, bees, beetles, &c., to fly in a large bell jar, one side of which was turned to the light, the other side being rendered opaque by dark pigment; by throwing young pigeons and birds from the hand into the air for the first time; by repeated observation of the flight of tame and wild birds; by stiffening, by tying up, and by removing portions of the wings of insects and birds; by an analysis of the movements of the travelling surfaces of quadrupeds, amphibia, and fishes; by the application of artificial fins, flippers, tails, and wings to the water and air; and by repeated dissections of all the parts, directly and indirectly, connected with flight.

Professor Marey obtained his results by gilding the extremities and margins of the wings of the insect with minute portions of gold leaf; by the application of the different parts (tip and anterior margin) of the wing of the insect to a smoked cylinder rotating at a given speed, the wing being made to record its own movements; by the captive and free flight of birds, which carried on and between their wings an apparatus which, by the aid of electricity, registered the movements of the wings on a smoked surface, travelling, at a known speed, in a horizontal direction; and by the employment of an artificial wing, constructed on the plan recommended by Borelli, Chabrier, Straus-Durckheim, Girard, and others.

The treatises on flight and cognate subjects by Dr. Pettigrew and Professor Marey are so elaborate and so profusely illustrated,[2] that a digest of them cannot fail to be interesting to the general reader, the more especially as in that digest we hope to state in a few words, and in something like chronological order, not only the great leading features of flight, but also the points wherein Dr. Pettigrew agrees with and differs from Professor Marey—these not being generally known.

The parts of Dr. Pettigrew's and of Professor Marey's works which interest us most are those which deal with aërial locomotion and the flight of the insect and bird.

Professor Marey, in his recent book,[3] describes the figure-of-8 movements made by the wing in space, and for these he claims, and in some journals has obtained, considerable *eudos*, although it is difficult to understand on what grounds.

There can be no question of the fact, that the figure-of-8 movements made by the wing in flight *were first*

[1] Reprinted from the *Quarterly Journal of Science*, April 1875.

[2] Dr. Pettigrew's memoirs alone contain over 200 original figures—those of Professor Marey considerably over 100.

[3] "Animal Mechanism: a Treatise on Terrestrial and Aërial Locomotion." By E. J. Marey, Professor at the College of France, and Member of the Academy of Medicine. Henry S. King & Co., 1874.

observed, described, and *delineated* by Dr. Pettigrew, and to this physiologist undoubtedly belongs the high merit of first discovering the true principles of flight.

Dr. Pettigrew published his discovery in the early part of 1867,[1] and Professor Marey did not write upon the subject of flight till the end of 1868.[2] There is, therefore, an interval of nearly *two years* in favour of Dr. Pettigrew.

We think it right to draw attention to this circumstance, because Professor Marey does scant justice to Dr. Pettigrew, and because we detect in all Professor Marey's writings on flight traces of Dr. Pettigrew's original discovery.

This remark applies equally to Professor Marey's theory and practice of flight.

We hope to be able to prove the validity of our position, as we advance, by a series of parallel passages. The history of science demands that this course should be taken. We begin with the figure-of-8 itself.

Professor Marey, in a letter addressed to the French Academy of Sciences, admitted Dr. Pettigrew's claim to priority in the matter of the figure-of-8 movements made by the wing in space in the following terms :—

"I have ascertained that, in reality, Mr. Pettigrew has seen before me, and represented in his memoir,[3] the figure-of-8 track made by the wing of the insect, and that the optic method to which I had recourse is almost identical with his. . . .

"I hasten to satisfy this legitimate demand, and I leave entirely to Mr. Pettigrew the priority over me relatively to the question, as restricted" (*Comptes Rendus*, May 16, 1870, p. 1093).

Since writing the above, Professor Marey has evidently been changing his views ; for in his new work ("Animal Mechanism," p. 187) he states that, "notwithstanding this apparent agreement, our theory, and that of Dr. Pettigrew, differ materially from each other."

We have searched diligently for the points of *disagreement*, and find them trifling in character and few in number. The points of *agreement*, on the other hand, are numerous and important.

Dr. Pettigrew, in his letter of "reclamation" to the French Academy,[4] to which the foregoing, by Professor Marey, is the reply, claims to have been the first to describe and illustrate the following :—

"1. That quadrupeds walk, and fishes swim, and insects, bats, and birds fly, by *figure-of-8* movements.

"2. That the flipper of the sea bear, the swimming wing of the penguin, and the wing of the insect, bat, and bird, are screws *structurally*, and resemble the blade of an ordinary screw propeller.

"3. That these organs are screws *functionally*, from their twisting and untwisting, and from their rotating in the direction of their length, when they are made to oscillate.

"4. That they have a reciprocating action, and *reverse their planes* more or less completely at every stroke.

"5. That the wing describes a *figure-of-8 track in space*, when the flying animal is artificially fixed.

"6. That the wing, when the flying animal is progressing at a high speed in a horizontal direction, describes a *looped* and then a *waved track*, from the fact that the figure-of-8 is gradually opened out or unravelled as the animal advances.

"7. That the *wing acts after the manner of a boy's kite*, both during the *down* and the *up* strokes."[5]

Such are briefly Dr. Pettigrew's views ; and if we compare what Professor Marey has written on flight with what Dr. Pettigrew here enunciates, we shall find the coincidences (to use no stronger terms) very striking.

Take the following passages from Professor Marey's recent work as examples :—

"If we gild a large portion of the upper surface of a wasp's wing, taking precautions that the gold leaf should be limited to this surface only, we see that the animal placed in the sun's rays *gives the figure-of-8* with a very unequal intensity in the two halves of the image. . . . It is evident that the cause of the phenomenon is to be found in *a change in the plane of the wing*, and consequently in the incidence of the solar rays. . . . We shall find in the employment of the graphic method new proofs of changes *in the plane of the wing* during flight. . . . [In this and other quotations the italics are ours.] It is therefore not necessary to look for special muscular actions to produce changes in the *plane of the wing ;* these in their turn will give us the key to the oblique *curvilinear movements which produce the figure-of-8 course* followed by the insect's wing" ("Animal Mechanism," pp. 188, 197).

In the passages here cited, Professor Marey admits, not only that the wing of the insect makes *a figure-of-8 track in space*, but also that the figure-of-8 is produced by *a change of plane in the wing*.

This is an important admission, for Professor Marey copies at page 201 of his book a figure-of-8 representation

[1] "On the Various Modes of Flight in Relation to Aeronautics" (*Proceedings of the Royal Institution of Great Britain*, March 22, 1867). "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom" (*Trans. Linn. Soc.*, vol. xxvi. ; read June 6 and 20, 1867).

[2] *Comptes Rendus*, tome lxvii., No. 26, p. 1341, Dec. 28, 1868.

[3] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom." By J. Bell Pettigrew, M.D., F.R.S. (*Trans. Linn. Soc.* vol. xxvi. ; read to Linn. Soc. on June 6 and 20, 1867.)

[4] *Comptes Rendus*, April 1870.

[5] "On the Physiology of Wings." By J. Bell Pettigrew, M.D., F.R.S. (*Trans. Roy. Soc. of Edinburgh*, vol. xxvi., p. 332.)

from Dr. Pettigrew's 1867 memoir,[1] in which this change of plane is delineated, and states that the arrows in Dr. Pettigrew's figure all point in one direction, and are wrongly placed. This is a glaring inaccuracy on the part of Professor Marey.

He has in the first place reversed the direction of the arrows in Dr. Pettigrew's figure, and in the second place he makes the half of the figure represent the whole. In Dr. Pettigrew's original figure the arrows are pointing from left to right; whereas in Professor Marey's copy of it, they are pointing from right to left.

In the description given of Dr. Pettigrew's figure, it is distinctly stated that *in extension* the arrows of the figure-of-8 are directed from left to right, but that *in flexion* they are directed from right to left.[2]

In one complete revolution of the wing, therefore, according to Dr. Pettigrew, the arrows are directed alternately from left to right, and from right to left, and this is precisely what happens in every figure-of-8 delineated by Professor Marey.

Dr. Pettigrew, when speaking of the change of plane occurring during the down and up strokes of the wing of the insect, states that:—

"A figure-of-8 compressed laterally, and placed obliquely with its long axis running from left to right of the spectator, represents the movement in question.

"The *down* and *up strokes*, as will be seen from this account, *cross each other*, the wing smiting the air during its descent from above, as in the bird and bat, and during its ascent from below, as in the flying fish and boy's kite.".[3]

A little further on, and on the same page of his 1867 memoir, in which the figure-of-8 and waved tracks made by the wing in stationary and progressive flight are delineated, Dr. Pettigrew says:—

"The figure-of-8 action of the wing explains how an insect or bird may fix itself in the air, the backward-and-forward reciprocating action of the pinion affording support, but no propulsion. In these instances the backward and forward strokes are made to counterbalance each other. . . . Although the figure-of-8 represents with considerable fidelity the twisting of the wing upon its axis during extension and flexion, when the insect is playing its wings before an object, or still better when it is artificially fixed; it is otherwise when the down stroke is added, and the insect is fairly on the wing, and progressing rapidly.

"In this case the wing, in virtue of its being carried forward by the body in motion, describes an undulating or spiral course."[4]

The figure-of-8 and undulating wave movements originally described and figured by Dr. Pettigrew, in March and June 1867, have been reproduced by Professor Marey in a variety of forms since December 1868. They are reproduced in a collective form in Professor Marey's work already referred to, published in 1874.

The importance of the figure-of-8 and wave movements cannot be over-estimated, and no one appears to be more keenly alive to their value than Professor Marey himself. When speaking of the figure-of-8 made by the wing in space, originally discovered by Dr. Pettigrew by the aid of the optical method, Professor Marey remarks:—

"We have seen, when treating of the mechanism of insect flight, that the fundamental experiment was that which revealed to us the course of the point of the wing throughout each of its revolutions. Our knowledge of the mechanism of flight naturally flowed, if we may so say, from this first notion."[5]

Professor Marey here admits that his knowledge of flight is derived from the figure-of-8 revealed by the optical method; but he admitted, as already stated, to the French Academy of Sciences, in May 1870, that the optical method to which he had recourse was nearly identical with that which Dr. Pettigrew employed, and that in reality Dr. Pettigrew had seen before him, and delineated the figure-of-8 track made by the wing of the insect in flight.

If, however, Dr. Pettigrew was the first to observe, describe, and delineate the figure-of-8 made by the wing in space; and if, as Professor Marey states, his knowledge of the mechanism of flight "naturally flowed . . . from this first notion," then it is quite evident, even according to Professor Marey's own showing, that the discovery of the true principles of flight was made by Dr. Pettigrew, and *not by him*. This follows as an inevitable sequence.

It is easy to extend a discovery once made, but the true discoverer is he who first describes and delineates the fundamental principle, and in the present instance that is unquestionably Dr. Pettigrew.

Dr. Pettigrew not only described and delineated the figure-of-8 and waved track made by the wing in space; he also described and figured the several changes of plane occurring in the wing during an entire revolution.

To him, moreover, is to be traced the important discovery of the *torsion* and *forward action* of the wing both during the down and the up strokes. The torsion and forward action of the wing are indispensable in flight.

[1] Marey's figure is "Fig. 86, Trajectory of the Wing," p. 201. Pettigrew's figure is at p. 233. (*Trans. Linn. Soc.*, 1867, vol. xxvi.)

[2] According to Dr. Pettigrew *extension* in the insect signifies "the carrying of the wing in a forward direction, away from the body; *flexion* meaning the reverse, or the drawing of the wing from before, backwards towards the body." (*Trans. Linn. Soc.*, vol. xxvi., p. 226.)

[3] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom."

[4] *Trans. Linn. Soc.*, vol. xxvi., p. 233.

[5] "Animal Mechanism," p. 234.

The body in flight is *dragged* forward, not pushed forward; but unless the wings themselves fly forward in curves, both during the down and up strokes, as Dr. Pettigrew explains, the body cannot be transmitted from one point to another. Dr. Pettigrew's experiments with natural and artificial wings are quite decisive on this point, as we have ourselves verified.

Dr. Pettigrew was likewise the first to describe and figure *the ellipse* formed by the wing of the bird, and to point out the difference in the direction of the stroke in the wing of the bird and insect, the stroke in the insect being, as a rule, *nearly horizontal*, that in the bird *nearly vertical*.[1]

Professor Marey, in his first paper on flight, communicated to the French Academy of Sciences,[2] delineates the wings of the wasp as making *vertical* figure-of-8 loops. Now this never happens in the wasp. The figure-of-8 loops made by the wing of the wasp, as Dr. Pettigrew has shown, are so oblique as to be *nearly horizontal.*

Professor Marey, in his latest work, has corrected this mistake,[3] and has delineated the horizontal figure-of-8 loops made by the wing of the insect in a figure nearly, if not identical, with a similar figure by Dr. Pettigrew.

Professor Marey's figure occurs at page 200 of his new work (1874), that of Dr. Pettigrew's at page 338 of his memoir, "On the Physiology of Wings" (*Trans. Roy. Soc. Edin.*, vol. xxvi., 1870).[4]

A careful comparison of the figures in question will show that Professor Marey's figure is, or may be, a transcript of Dr. Pettigrew's. And this remark applies not only to the figure as a whole, but to all its details; first, to the horizontal direction of the figure-of-8 loops, made by the wing in space; secondly, to the reversal of the planes of the wing as the wing flies to and fro, *i.e.* during a revolution; and thirdly, to the varying angles made by the surfaces of the wing with the horizon, when the wing is made to vibrate.

Surely this is more than a mere coincidence!

Then how strangely Professor Marey has blundered as to the direction of the stroke, when this is vertical. Thus he represents the wing (p. 195, Fig. 82) as descending in a *downward* and *backward* direction, and as ascending in an *upward* and *backward* direction. Now this is simply a *physical* impossibility, and clearly shows that Professor Marey has failed to interpret the tracings obtained from the wing by his so-called graphic method.

The arrows in Professor Marey's figure-of-8 (*vide* Fig. 82), depicting the movements of the wing in space, should, in reality, be reversed. To get a continuous series of figure-of-8 loops, or of forward curves, characteristic of progressive flight, the wing must descend and ascend always *in a forward direction*, as described and figured by Dr. Pettigrew.[5] The tracings obtained by Professor Marey himself show this conclusively.

At page 201 of the work under consideration, Professor Marey describes his artificial wing as consisting of a *rigid main rib* in front and a flexible sail behind, from which it follows that he is not even now aware that a natural wing, and a properly constructed artificial one, are *flexible* and *elastic throughout.*

Professor Marey is wrong, when he states that the anterior margin of the wing of the insect *is rigid.* The following are his words:—

"These experiments prove that the insect needs, for the due function of flight, a *rigid main rib* and a flexible membrane. If we cover the flexible part of the wing with a coating which hardens as it dries, *flight is prevented.* We hinder it also *by destroying the rigidity of the anterior nervure*" (p. 208).

Dr. Pettigrew, in his memoir "On the Physiology of Wings," expresses the facts in very few words:—

"The wing of a flying creature . . . *is not rigid.*[6] . . . That the anterior margin of the wing should not be composed of a rigid rod may be demonstrated in a variety of ways. If a rigid rod be made to vibrate by the hand, the vibration is not smooth and continuous; on the contrary, it is irregular and jerky, and characterised by two *pauses*, the one occurring at the end of the *up stroke*, the other occurring at the end of the *down stroke.* The wing to be effective as an elevating and propelling organ should have no dead points, and should be characterised by a rapid winnowing or fanning motion. . . . If a longitudinal section of bamboo cane has added to it tapering

[1] The following is the account given by Dr. Pettigrew: "The direction of the stroke varies slightly according to circumstances, but it will be quite proper to assume that the wing of the insect is made to vibrate in a more or less *horizontal* direction, and that of the bird or bat in a more or less *vertical* direction. By a slight alteration in the position of the body, or by a rotation of the wing in the direction of its length, the vertical direction of the stroke is converted into a horizontal direction, and *vice versâ.* The facility with which the direction of the stroke is changed is greatest in insects; it is not uncommon to see them elevate themselves by a figure-of-8 *horizontal* screwing motion, and then suddenly changing the horizontal screwing into a more *vertical* one, to dart rapidly forward in a curved line." (*Trans. Roy. Soc. Edin.*, vol. xxvi., p. 335.)

[2] "Physiologie—Détermination éxperimentale du mouvement des ailes des insectes pendant le vol." Par M. E. J. Marey. (*Comptes Rendus*, tome lxvii., No. 26, December 28, 1868, p. 1341.)

[3] Professor Marey remarks: "We need only observe the flight of certain insects, the common fly for instance, and most of the other Diptera, to see that the plane in which the wings move *is not vertical*, but, on the contrary, *very nearly horizontal.*" ("Animal Mechanism," 1874, p. 204.)

[4] Figs. 5 and 6 more especially.

[5] According to this authority, "a natural wing, or a properly constructed artificial one, cannot be depressed either *vertically downwards*, or *downwards* and *backwards.* It *will* (the writer would say *does*) of necessity descend *downwards* and *forwards in a curve.* This arises from its being flexible and elastic throughout, and in especial from its being carefully graduated as regards thickness, the tip being thinner and more elastic than the root, and the *posterior margin* than the *anterior margin.*"

[6] This is again insisted upon in "Animal Locomotion," p. 240, where Dr. Pettigrew remarks, when speaking of the construction of an artificial wave wing on the insect type, "It should be *flexible and elastic throughout.*"

rods of whalebone which radiate in an outward direction, and this (framework)[1] be covered by a thin sheet of india-rubber (gutta-percha tissue), an artificial wing, resembling the natural one in all its essential points, is at once produced. . . . If this wing be made to vibrate by its root, a series of longitudinal and transverse waves are at once formed, the one series running in the direction of the *length of the wing*, the other in the direction of its *breadth*. The wing further *twists* and *untwists* during the down and up strokes. . . . This form of wing, which may be regarded as the realisation of the figure-of-8 theory of flight, elevates and propels both during the down and up strokes, and its working is accompanied with almost no slip. It seems literally to float upon the air."[2]

"*No wing that is rigid in the anterior margin can twist and untwist during its action, and produce the figure-of-8 curves generated by the living wing.* To produce the curves in question, the wing must be flexible, elastic, and capable of change of form in all its parts."[3]

In one part of his new work, indeed (viz. at p. 198), Professor Marey seems to have largely profited by the observations and experiments of Dr. Pettigrew, as given above; for he states that, if rapid to-and-fro movements in a vertical plane be given to a "*flexible shaft*" (mark, the shaft is no longer described as *rigid*), to which he affixes a membrane similar to that found in the wings of insects—to use his own words—"this *flexible shaft* will then represent the main rib of the wing; and we shall see this contrivance execute all the movements which the wing of the insect describes in space." "If," he says, "we illuminate the extremity of this artificial wing, we shall see that its point describes the figure 8 like a *real wing;* we shall observe also that *the plane of the wing changes twice during each revolution*, in the same manner as in the insect itself" ("Animal Mechanism," p. 198).[4]

Professor Marey, it will be observed, claims for his artificial wing similar properties to those originally claimed by Dr. Pettigrew for his artificial wing. Thus Dr. Pettigrew states (op. cit., pp. 421, 422), that if the anterior or thick margin of his artificial wave wing be directed upwards, and the wing made to vibrate, it will fly in *an upward direction* with an undulating motion; that if the anterior or thick margin of the wing be directed downwards, the wing will describe a waved track and fly *downwards;* and if the under surface of the wing makes no angle, or a very small angle with the horizon, it will dart forward in a series of curves *in a horizontal direction.*

Similarly, Prof. Marey says (p. 207) that if the anterior margins of the main ribs of his artificial insect be inclined upwards, the insect *rises vertically*, and that if the anterior margins of the main ribs be turned downwards *a descending vertical force is developed;* and that if the main ribs be turned upwards, and slightly forward, it develops the force *which sustains it in the air*, and directs its course in space.

We may point out many other parallel passages. Dr. Pettigrew states (op. cit., p. 335):—

"The direction of the stroke varies slightly, according to circumstances; but it will be quite proper to assume that the wing of the insect is made to vibrate in a more or less *horizontal direction*, and that of the bird and bat in a more or less *vertical direction.* By a slight alteration in the position of the body or by a rotation of the wing in the direction of its length, the vertical direction of the stroke is converted into a horizontal direction, and *vice versâ.*

"The facility with which the direction of the stroke is changed is greatest in insects; it is not uncommon to see them elevate themselves by a figure-of-8, *horizontal* screwing movement, and then, suddenly changing the horizontal screwing into a more vertical one, to dart rapidly forward in a curved line."

Compare with the foregoing the following from Professor Marey's new work (p. 207):—

"When an insect hovers over a flower, and we see it illuminated obliquely by the setting sun, we may satisfy ourselves that the plane of oscillation of its wings is *nearly horizontal.* This inclination must evidently be *modified* as soon as the insect wishes to dart off rapidly in any direction; but then the eye can scarcely follow it and detect the change of plane, the existence of which we are compelled to admit by the theory and the experiments already detailed."

When speaking of the wing of the bird, Dr. Pettigrew points out (*Trans. Linn. Soc.*, vol. xxvi., p. 242) that—

"The anterior or thick margin of the wing and the posterior or thin margin present different degrees of curvature, so that under certain conditions the two margins cross each other, and form *a true helix.* The anterior margin presents two well-marked curves, a corresponding number being found on the posterior margin.

"These curves may, for the sake of clearness, be divided into *axillary* and *distal* curves; the former occurring towards the root of the wing, the latter towards the extremity.

"The anterior axillary and distal curves completely reverse themselves during the acts of extension and flexion, and so of the posterior axillary and distal curves."

[1] The words in brackets are ours. [2] *Trans. Roy. Soc. Edin.*, vol. xxvi., 1870, pp. 408, 419, 420, and 423.

[3] "Physiology of Wings," by J. Bell Pettigrew, M.D., F.R.S., p. 422. (*Trans. Roy. Soc. Edin.*, vol. xxvi., 1870.)

[4] The above remarks of Professor Marey are worth studying, for two reasons: first, because they are so confirmatory of all Dr. Pettigrew had written about the *flexibility* of the main nervure of an insect's wing; secondly, they contrast so strangely with the *rigid* main rib, at pp. 201 and 208 of Marey's work before cited.

In like manner Prof. Marey, in his *first* chapter on the flight of birds (at p. 210), says that—

"If we take a dead bird and spread out its wings . . . we see that, at different points in its length, the wing presents *very remarkable changes of plane.* At the inner part, towards the body, *the wing inclines considerably both downwards and backwards,* while near its extremity it is *horizontal,* and *sometimes slightly turned up,* so that its under surface is directed somewhat backward." [1]

It is worthy of remark that the curves of the wing described and delineated by Dr. Pettigrew are reproduced by Prof. Marey (compare Figs. 68, 69, and 70 of Dr. Pettigrew's 1867 memoir, *Linn. Soc. Trans.*, vol. xxvi., with the right wing, Fig. 89, p. 210, of Prof. Marey's new volume).

When speaking of the duration of the down and up strokes, Dr. Pettigrew observes (*Trans. Linn. Soc.*, vol. xxvi., p. 261) :—

"In birds which glide or skim, it has appeared to me that the *wing is recovered much more quickly,* and *the downward stroke is delivered much more slowly,* than in ordinary flight; in fact, that the rapidity with which the wing acts in an upward and downward direction is, in some instances, more or less reversed; and this is what we would naturally expect if we recollect that in gliding the wings require to be, for the most part, in the expanded condition."

Prof. Marey writes in a similar strain. He states :—

"Experiment proves that the wing of the bird is raised more quickly than it descends" (p. 212). . . . "Contrary to the opinion entertained by some writers, *the duration of the depression of the wing is usually longer than that of its rise.* The inequality of these two periods is more distinctly seen in birds whose wings have a surface and which beat slowly" (p. 228).

Weight, according to Dr. Pettigrew, contributes to horizontal flight. In illustration he states (*Trans. Roy. Soc. Edin.*, vol. xxvi., pp. 355, 356) :—

"If two quill-feathers are fixed in an ordinary cork, and the apparatus allowed to drop from a height, the cork does not fall vertically downwards, but *downwards and forwards in a curve.* When artificial wings, constructed on the principle of natural ones, are allowed to drop from a height, they *describe double curves* in falling, the roots of the wing reaching the ground first, which proves the greater buoying power of the tips of the wings. Weight, when acting upon wings, must be regarded as an independent moving power." . . . "The *wings of the bird form a natural parachute,* from which the body depends both during the down and up strokes" (p. 371).

Prof. Marey performs similar experiments, and arrives at similar conclusions. Thus he explains (p. 217) that if a sheet of paper folded in the middle, with a wire loaded at one end and fixed in the bent portion, be allowed to fall, the apparatus will not descend vertically, but will follow an *oblique trajectory*; and that if the corners of the paper be bent, and the concavity directed downwards, the apparatus will in falling describe a *double curve.*

"The wings are attached exactly at the highest part of the thorax, and consequently, when the outstretched wings act upon the air as a fulcrum, all the weight of the body is placed below this surface of suspension. Thus the heaviest part is placed as low as possible beneath the point of suspension. The bird, as it descends with its wings outspread, will thus present its ventral region downwards, without its being necessary to make an effort to keep its equilibrium; it will take this position passively, *like a parachute set free in space,* or like the *shuttlecock when it falls upon the battledore*" ("Animal Mechanism," p. 216).

Dr. Pettigrew likens the wing of the bird to a boy's kite (*Proc. Roy. Inst. of Great Britain,* March 22, 1867) :—

"The wing of the bird *acts after the manner of a boy's kite,* the only difference being that the kite is pulled forwards upon the wind *by the string and the hand,* whereas in the bird the wing is pushed forwards on the wind by *the weight of the body* and the life residing in the pinion itself."

Similar in substance is the subjoined passage from Prof. Marey (p. 220) :—

"In the last two forms, the wing, directed more or less obliquely, derives its point of resistance from the air, *like the child's plaything called a kite,* but with this difference—that the velocity is given to the kite by *the tractile force exerted on the string* when the air is calm, while the bird when it hovers utilises the speed which it has already acquired either by *its oblique fall* or by the previous flapping of its wings."

Dr. Pettigrew attaches great importance to the activity of the wing and its small size. Thus he remarks (*Trans. Roy. Soc. Edin.*, vol. xxvi., p. 408) :—

"*The surface exposed by a natural wing,* when compared with the great weight it is capable of elevating, *is remarkably small.* This is accounted for by the length and *great range of motion* of natural wings, the latter enabling the wings to convert large tracts of air into supporting areas. It is also accounted for by the *multiplicity of the movements of natural wings,* these enabling the pinions to create and rise upon currents of their own forming,

[1] It is evident from the succeeding paragraph to above quotation from "Animal Mechanism," that Prof. Marey had read Dr. Pettigrew's observations to which we have just referred.

and to select and utilise existing currents." . . . "The *problem of flight would seem to resolve itself into one of weight, power, velocity, and small surfaces*, as against comparative levity, debility, diminished speed, and extensive surfaces" (p. 386).

Analogous in many respects to the foregoing is the following from Prof. Marey (p. 222) :—

"The part played by the wing in flight is not merely passive, for a sail or a parachute ought always to have a surface in proportion to the weight which it has to support ; but, on the contrary, when considered in its proper point of view, *as an organ which strikes the air*, the wing of the bird ought, as we shall see, to present a surface *relatively less in birds of a large size and of great weight*."

Again :—

"Animals of large size and great weight sustain themselves in the air *with a much less proportionate surface of wing* than those of smaller size" (p. 222).

Dr. Pettigrew dwells upon the relative speed attained by the different parts of the wing (*Trans. Roy. Soc. Edin.*, vol. xxvi., pp. 399–442). He says the wing as a rule is long and narrow.

"As a consequence *a comparatively slow and very limited movement at the root confers great range and immense speed at the tip*, the speed of each portion of the wing increasing as the root of the wing is receded from." . . . "The small humming-bird, in order to keep itself stationary before a flower, requires to oscillate its tiny wings with great rapidity, whereas the large humming-bird can attain the same object by flapping its large wings with a very slow and powerful movement." . . . "In the larger birds the movements are slower in proportion to the size, and more especially in proportion to the length, of the wing. This leads me to conclude that *very large wings may be driven with a comparatively slow motion*."

Professor Marey illustrates the same points as under (p. 224) :—

"It is not immaterial whether the surface which strikes the air has its maximum near the *body* or near the *extremity ; these two points have very different velocities.* For an equal extent of surface the resistance will be greater at the point of the wing than at its base."

Again (p. 226) :—

"It can be proved that, if the strokes of the wing were as frequent in large as in small birds, each stroke would have a velocity whose value would increase with the size of the bird ; and as the resistance of the air increases, for each element of the surface of the wing, according to the square of the velocity of that organ, *a considerable advantage would result to the bird of large size, as to the work produced upon the air*."

Dr. Pettigrew shows that the vigour with which the wing is propelled varies according as the bird is rising, falling, or progressing in a horizontal direction (*Trans. Linn. Soc.*, vol. xxvi., pp. 227, 260, 261). He observes :—

"All birds which do not, like the swallow and humming-birds, drop from a height, raise themselves at first by a vigorous leap, in which they incline their bodies in an upward direction. *By a few sweeping strokes*, delivered downwards and forwards, in which the wings are nearly made to meet above and below the body, they lever themselves upwards and forwards, and in a surprisingly short space of time acquire that degree of momentum which greatly assists them in their future career." . . . "The forward movement of the wing during the down or effective stroke is particularly evident in birds when rising, the wing on such occasions being urged with *unusual vigour*" (p. 227, op. cit.).

"When the bird has elevated itself to the desired height, *the length of the downward stroke is generally curtailed*, the mere extension and flexion of the wing, assisted by the weight of the body, in some cases sufficing for the ordinary purposes of flight. This is especially the case if the bird is advancing against a slight breeze" (pp. 260 and 261). "If birds wish to descend, they may reverse the direction of the inclined plane, and plunge head foremost with extended wings ; or they may flex the wings, and so accelerate their pace ; or they may raise their wings, and drop parachute fashion ; or they may even fly in a downward direction—*a few sudden strokes*, a more or less abrupt curve, and a certain degree of horizontal movement, being in either case necessary to break the fall previous to alighting" (p. 262, op. cit.).

Prof. Marey, as the annexed passages show, also adverts to the relative frequency and force with which the wing is urged in ascending, descending, and horizontal flight, though less fully than Dr. Pettigrew does :—

"The frequency of the strokes of the wing varies also according as the bird is first starting, in full flight, or at the end of its flight" (p. 228, "Animal Mechanism").

Again :—

"Confining the question within these limits, experiment shows that the strokes of the bird's wing *differ in amplitude and in frequency* from one moment to another as they fly. When they first start *the strokes are rather fewer, but much more energetic ;* they reach, after two or three strokes of the wing, *a rhythm almost regular, which they lose again when they are about to settle*" (p. 234, op. cit.).

Dr. Pettigrew lays especial emphasis on the elliptical movements made by the wing of the bird (*Trans. Linn. Soc.*, vol. xxvi.). Thus he remarks :—

"During extension the elbow and bones of the forearm, particularly their distal extremities, describe an *upward curve.* During flexion the elbow and bones referred to describe another but *opposite curve.* The movements described by the elbow-joint during extension and flexion may consequently be represented by an *ellipse or ovoid*" (p. 248, op. cit., Diagrams 8 to 13 more especially).

Prof. Marey follows Dr. Pettigrew in the matter of these elliptical movements. He says :—

"During the whole of the bird's flight the registering lever described *a kind of ellipse.*" . . . "All our experiments have shown that birds of different species describe with their wings *an elliptical trajectory*" (p. 242).

Again :—

"In fact, the bone of the wing in each describes a kind of *irregular ellipse*, with its greater axis inclined *downwards and forwards.*"

Dr. Pettigrew represents the wing of the bird as oscillating on two separate axes—the one running parallel with the bird, the other at right angles to it—and adds (in his 1867 memoir to the Linnean Society, p. 243) :—

"The wing may be said to agitate the air in two principal directions, viz. from *within outward or the reverse*, and from *behind forward or the reverse*, the agitation in question producing two powerful pulsations—a longitudinal and a lateral."

Prof. Marey gives, more briefly but yet in very similar terms, the same statement. He says (p. 247) :—

"That a bird passes through a *double oscillatory movement*, in a vertical plane, for each revolution of its wings."

Dr. Pettigrew describes and delineates the wing of the bird as advancing in a curved line, both when it rises and falls. He observes (*Trans. Linn. Soc.*, vol. xxvi., pp. 214 and 233) :—

"In the water the wing strikes *downwards and backwards* (and acts as an auxiliary of the foot), whereas in the air it strikes *downwards and forwards*. . . . To counteract the tendency of the bird in motion to fall in a downward and forward direction, the stroke is delivered in the direction in which falling would naturally occur—the kite-like action of the wing, and the rapidity with which it is moved, causing the mass of the bird to pursue a more or less horizontal direction. I offer this explanation of the action of the wing in and out of the water after repeated and careful observation in tame and wild birds, and, as I am aware, in opposition to all previous writers on the subject."

Prof. Marey again corroborates Dr. Pettigrew's original observations, as the subjoined extract from "Animal Mechanism" will show (p. 254) :—

"The inspection of the curve shows us also that the pigeon's wing was carried more especially in the direction of the upper parts, similar to the point A ; in other terms, that *the forward predominated over the backward movement.*"

Dr. Pettigrew describes and figures the body of the bird in flight as alternately rising and falling in forward curves, the curves described by the body being the opposite of those described by the wing, those movements being due to a kite-like action of the wings (*Trans. Roy. Soc. Edin.*, vol. xxvi., pp. 343, 344). Thus Dr. Pettigrew remarks :—

"It is a condition of natural wings, and of artificial wings constructed on the principle of living wings, that, when forcibly elevated or depressed, even in a strictly vertical direction, they inevitably dart forward. In both cases the wing describes *a waved track*, which clearly shows that the wing strikes downwards and forwards during the down stroke, and upwards and forwards during the up stroke. The wing, in fact, is always advancing, *its under surface attacking the air like a boy's kite.*" . . . "As the body of the insect, bat, and bird, falls forward in a curve when the wing ascends, and is elevated in a curve when the wing descends, it follows that *the trunk of the animal is urged along a waved line.* I have distinctly seen the alternate rise and fall of the body and wing, when watching the flight of the gull from the stern of a steamboat."

Professor Marey writes in a very similar strain. He asks (pp. 264, 265) :—

"But do we find that the bird, when suspended in the air, keeps at a constant level, or *does it pass through oscillations in the vertical plane?* Do we not experience, by the intermittent effect of the flapping of its wings, *rising and falling motions*, of which the eye can detect neither the frequency nor extent ? Again, does not the bird advance in its onward course, with variable rapidity ? Shall we not find in the action of its wings a *series of impulses*, which give to its advancing course a *jerking motion?* These queries can be answered experimentally." . . . "To explain the ascent of the bird during the time of the elevation of the wing, it seems indispensable to refer to *the effect of the child's kite*, to which we have before alluded. The bird, having acquired a certain velocity, presents its wings to the air *as inclined planes.*" . . . "Thus, by registering at the same time the two orders of oscillation in the flight of a buzzard, we find that the phase of *depression of the wing produces* at the same time

the *elevation of the bird* and the acceleration of its horizontal swiftness" (p. 269). . . . "A part of this resistance, viz. that which is applied to *the lower surface of the wing*, is utilised to sustain the bird by the kind of action which we have compared to that of *a child's kite.* It appears that this action is of primary importance in the flight of the bird" (p. 275). . . . "In the bird, one of the phases of the movement of the wing is, to a certain extent, passive; that is to say, it receives the pressure of the air *on its lower surface, when the bird is projected rapidly forward by its acquired velocity.* Under these conditions, the whole bird being carried forward in space, all the parts of the wing are moved with the same rapidity, to take advantage of the action of the air, *which presses on them as on a kite*" (p. 276).

Dr. Pettigrew explains that the wing is a screw structurally and functionally; that it revolves on two axes (the one running in the direction of the length of the wing, the other in the direction of its breadth), and that the action of the wing resembles the action of an oar in sculling (*Trans. Linn. Soc.*, vol. xxvi., pp. 206, 229, 231, and 266; *Proc. Roy. Inst. of Great Britain*, March 22, 1867). Thus, he states that:—

"In the fish, the lower half of the body and the broadly expanded tail are applied to the water *very much as an oar is in sculling*. . . . The fish may be said to drill the water in two directions, viz. from behind forward, by a *twisting or screwing* of the body on its long axis, and from side to side by causing its anterior and posterior portions to assume opposite curves. The pectoral and other fins are also thrown into curves in action, the movement, as in the body itself, travelling *in spiral waves;* and it is worthy of remark that the wing of the insect, bat, and bird obeys similar impulses.

"The fins *are rotated or twisted*, and their free margins lashed about by spiral movements, which closely resemble those by which the wings of insects are propelled. . . . That the wing *twists upon itself structurally*, not only in the insect, but also in the bat and bird, any one may readily satisfy himself by a careful examination; and that it *twists upon itself during its action* I have had the most convincing and repeated proofs." "The wing of the bird acts *as a twisted inclined plane.* In this respect it intimately agrees with the wing of both the insect and bat. . . . The twisting in question is most marked in the posterior, or thin margin of the wing, the anterior or thicker margin performing more *the part* of *an axis.* As the result of this arrangement, the anterior or thick margin cuts into the air quietly, and as it were by stealth, the posterior one producing on all occasions *a violent commotion*, especially perceptible if a flame be exposed behind the insect."

Professor Marey goes over the same ground in much the same way. Thus, at pp. 107, 109, 198, 208, 210, 211, 259, and 261, he states:—

"The oar is found in many insects which move on the surface of the water. A contrivance is employed by other animals, which resembles the action of an oar used at the stern of a boat in the process called *sculling.* To the latter motive power may be referred all those movements in which *an inclined plane* is displaced in the liquid, and finds in the resistance of the water which it presses obliquely two component forces, of which one furnishes a movement of propulsion." . . . "When a fish strikes the water with his tail, in order to drive himself forward, he executes a double work; a part tends to drive behind him a certain mass of fluid with a certain velocity, and the other to drive the animal forward, in spite of the resistance of the surrounding water. . . . *Aërial Locomotion.*—This mechanism is still the same, the motion of *an inclined plane*, which causes motion through the air; the wing, in fact, in the insect as well as in the bird, strikes the air *in an oblique manner*, repels it in a certain direction, and gives the body a motion directly opposite." . . . "Each stroke of the wing *acts upon the air obliquely*, and neutralises its resistance, so that a horizontal force results, which impels the insect forward. An effect is produced analogous with that which takes place when an oar is used in the stern of a boat in the *action of sculling.*" "Most of the propellers which act in water overcome the resistance of the fluid by the action of *an inclined plane.* The tail of the fish produces a propulsion of this kind. *Even the screw may be considered as an inclined plane*, whose movement is continuous, and always in the same direction. . . . We see the main rib (anterior margin) of the wing remain *sensibly immovable, and around it turns the membranous portion* (posterior margin)." . . . "If this motion as on a pivot did not exist, the wing would cut the air with its edge, and would be utterly incapable of producing flight." . . . "The wing presents *very remarkable changes* of *plane* at the *inner part towards* the body; the wing *inclines considerably, both downwards* and *backwards;* while near its extremity it is *horizontal and somewhat slightly turned up.*" . . . "We admit that the wing *revolves on an axis.*" . . . "It was necessary, therefore, for the lever, while fixed to the feathers of the bird, to glide freely on the rod in the direction of its length; and yet that it should cause it to receive, under the *form of torsion*, all the changes of inclination that are transmitted to it by the wings of the bird." . . . "For this purpose we must return *to the dotted figure* 8, which is the impression of the *torsions of the wing* of the different instants."

Dr. Pettigrew points out that the wing acts as a true kite, both during the down and up strokes. He remarks (*Trans. Roy. Soc. Edin.*, vol. xxvi., p. 343):—

"If, as I have endeavoured to explain, the wing, even when elevated and depressed in a strictly vertical direction, inevitably and invariably darts forward, it follows, as a consequence, that the wing flies forwards as a true kite, both during the down and up strokes, and that its *under concave, or biting surface*, in virtue of the forward travel communicated to it by the body in motion, is *closely applied to the air, both during its ascent and descent;* a fact hitherto overlooked, but one of considerable importance, as showing how the wing furnishes a persistent buoyancy alike when it rises and falls. The angle made by the wing of the bat and bird with the horizon is constantly varying, as in the insect wing."

Professor Marey, in his earlier writings (*Revue des Cours Scientifiques de la France et de l'Étranger*, Mars, 1869), describes the wing as making *a backward angle of* 45° *with the horizon during its descent, and a forward angle of* 45° *during its ascent.*

This view was shown by Dr. Pettigrew to be untenable, and we find it greatly modified in Professor Marey's later work. Thus, at Fig. 111, p. 263, where the angles of inclination made by the wing during its rise and fall are given, the under surface of the wing is represented as *forming a kite*, during quite three-fourths of one entire revolution of the wing.

At no point is the wing represented as making, during its descent, *a backward angle of* 45°. Nor is this all. At p. 274, Professor Marey states that—

"In free flight the axis of the bird is horizontal, or rather, *turned somewhat upward*. Restored to this proper position, a fresh direction would be given to each of the positions of the wing. Then, probably, we should see that the wing always *presents its lower surface to the air*, as the only one which can find in it a point of resistance."

In this modified statement, as may readily be perceived, we have simply a repetition of Dr. Pettigrew's view, viz. "*that the under surface of the wing acts as a kite, both when the wing rises and falls.*"

We might greatly multiply these parallel passages in proof of our original assertion, that in all Professor Marey's writings and experiments in flight, *Dr. Pettigrew's original discoveries and experiments may be traced*, and we may fairly emphasise our other statement, "*that Professor Marey has done scant justice to Dr. Pettigrew.*"

This is the more evident, as we are given to understand that Dr. Pettigrew's original memoirs and papers were duly transmitted to Professor Marey immediately after their publication.

From the foregoing, it will be evident that Professor Marey has added comparatively little to the science of aërostation. He has, for the most part, simply confirmed by experimental methods, in which he is an adept, Dr. Pettigrew's original observations and experiments, published nearly two years before his own experiments were undertaken.

Professor Marey is certainly not entitled to say, as he does at p. 187, that "*notwithstanding this apparent agreement, our theory and that of Dr. Pettigrew differ materially from each other.*"

Still less is he entitled, virtually, to appropriate Dr. Pettigrew's descriptions and figures, without full and fair acknowledgment. Least of all is he entitled to modify and misrepresent those descriptions and figures.

Such practices sap the foundation of science.

APPENDIX III

SPIRAL FORMATIONS IN RELATION TO WALKING, SWIMMING, AND FLYING[1]

The universality of the spiral in nature is a subject alike for surprise and reflection. As regards beauty of outline, the spiral transcends all other forms, and is a source of pleasure. The spiral occurs very frequently both in the inorganic and organic kingdoms, and, as I hope to show in the present article, has its own special uses. It is seen on a grand scale in the spiral arrangements of nebulæ, in the whirlwind and whirlpool, in the waterspout and the sand-storm, in the cyclone, and other natural phenomena. As concerns living things it is fundamental, and manifests itself in the most rudimentary plants and animals, in the cells and seeds of the higher plants, and in the spermatozoids of the more complex animals. It makes its appearance, so to speak, at the very threshold of life, and can be traced through the whole vegetable and animal kingdoms up to man himself. It is seen in spiral stems, spiral tendrils, spiral leaves, spiral flowers, spiral fruits, &c., in plants, and in spiral bones and joints, spiral muscles, spiral horns, spiral teeth, spiral shells, &c., in animals. It not only abounds in every department of plant life but it also lends itself freely to the construction of large numbers of external and internal skeletons in animals. All the hard and soft parts of the higher animals are, with few exceptions, dominated by it. It is a thing not of accident but of design.

Apart from the beauty and grace which inhere in every variety of spiral I think I can trace in it a hidden and far-reaching purpose. Indeed, I can show that not only do spirals enter largely into the formation of plants and animals, but also that the complicated movements of climbing plants and tendrils and of walking, swimming, and flying are directly traceable to their existence; nay, more, that the circulation of the blood in birds and mammals is in great measure due to the ventricles of the heart being composed of powerful combinations of spiral muscular fibres. As a matter of fact, the blood in birds and mammals is forced by the ventricles into the larger blood-vessels (especially the aorta) by spiral movements which cause it to gyrate within them much in the same way that a rifle bullet is made to gyrate within a rifle when the weapon is discharged. The ancient and grim phrase "wringing the heart's blood" has, curiously enough, its foundation in fact. The spiral ventricles of the heart in birds and mammals are typical of many other structures. In the human species the stomach, bladder, uterus, &c., are all composed of spiral, figure-of-8 muscular fibres: and, strange as it may appear, the food, the urine, and even the fœtus, are subjected to spiral pressure when being passed on and extruded. In parturition in the human female the offspring make a distinctly spiral exit, a result produced partly by the movements of the uterus and partly by the configuration of the pelvis. The heart is at once the most spiral and powerful muscle in the body, if the amount of work performed by it and its unceasing activity be taken into account. The ventricles of the heart are also by far the most complicated muscles known. Their arrangement forms a veritable Gordian knot in anatomy, the famous anatomists, Vesalius, Albinus, Haller, and De Blainville all confessing their inability to unravel it. The ventricles of the heart are deserving of very particular attention, both as regards their structure and function, from the fact that they throw a flood of light on muscular arrangements and movements as a whole.

All muscles, voluntary and involuntary, are fundamentally spiral in their nature. Sometimes only a curve or portion of a spiral can be distinguished, at other times entire systems of double reversing spirals can be made out. The involuntary muscular fibres of the ventricles of the heart in the bird and mammal afford beautiful examples of complicated double spirals, and one has only to study the spiral configuration of the bones (especially the long bones) as seen in the extremities of birds and mammals, and the spiral configuration of the joints connected therewith, to be convinced that the voluntary muscles must not only be spirally arranged but that they must also act spirally. The spiral action of the voluntary muscles is most observable where they act upon spiral joints, but it is also well seen where they act upon universal or ball-and-socket joints, such as the shoulder and hip-joints. It

[1] Reprinted from *The Lancet*, January 2, 1904.

is in virtue of the spiral action of the muscular masses connected with ball-and-socket and with spiral hinge and other joints that circumduction and partial rotation of the arms and legs are possible. It is a curious fact that the muscular masses which invest and actuate ball-and-socket joints have their fibres arranged very much as the muscular fibres of the ventricles of the heart in birds and mammals are arranged—that is, they run in vertical, oblique, and transverse spiral directions. The muscles of the pharynx, œsophagus, and tongue follow the same general plan. The voluntary and involuntary muscles, it will be seen, are arranged in spiral cycles, the only difference between the two kinds of muscles being that in certain of the hollow viscera, say the ventricles of the heart of the bird and mammal, the involuntary muscles are arranged round *spiral cavities*, whereas the voluntary muscles, say those occurring in the extremities of the bird and mammal, are arranged round *spiral bones and spiral and other joints.* The involuntary hollow muscles communicate, as stated, a spiral impulse to the substances contained within them; the voluntary solid muscles, on the other hand, cause the extremities and other parts of the body to make spiral movements and describe spiral trajectories.

Muscles, whether voluntary or involuntary, in every instance act harmoniously and to given ends. Their movements are never perfunctory or haphazard. There is no such thing as flexor muscles forcibly and violently dragging out extensors, pronators supinators, abductors adductors, and the converse. This would be a mere waste of power, as it would necessitate one muscle contending with another, while each muscle has the same object in view—namely, the moving of certain bones or parts. When the flexor muscles shorten or contract the extensor muscles elongate or relax. This they do by simultaneous centripetal and centrifugal movements. Not only do the voluntary muscles act together and in groups, but they require to be trained to prevent antagonistic action. Walking, swimming, and flying have all to be learned, and the training consists in teaching the several muscles and groups of muscles to act in concert at stated intervals. Antagonism in muscular action would be fatal to the performance of muscular work. As a matter of fact, all muscles are invested with a double vital power whereby they can shorten and elongate, or, what is the same thing, close and open, by alternate centripetal and centrifugal movements, the flexor muscles closing and shortening when the extensor muscles open and elongate, and *vice versâ.*

In no part of the body do curves and spirals play a more prominent part than in the spinal column, the pelvis, shoulders, and extremities. In man the spinal column consists of four exquisite curves, the convexities of the cervical and abdominal curves being directed forward and the convexities of the thoracic and pelvic curves being directed backward. This double system of curves diffuses shocks equally from above and below, and presents a line of beauty not matched even by that of the famous limner, Hogarth. The pelvis consists of a series of most beautiful arches (some of them skew), and the bones composing the arches are twisted in various directions. Similar remarks apply to the scapulæ, the clavicles, and the ribs. The bones of the extremities, as already pointed out, are spiral in their nature, but they are also in the majority of cases slightly bent in the direction of their length, a circumstance which contributes greatly alike to their elasticity and to their strength. Additional strength and elasticity are obtained, in the case of the arm and thigh bones (humerus and femur), by the bones being provided with short, oblique necks where they articulate with the body, an arrangement calculated to neutralise impacts of all kinds from the hands, feet, and other parts of the extremities.

In virtue of the spiral arrangements which obtain in the muscles and in the bones and joints of the extremities the limbs of bipeds and quadrupeds in walking and running describe alternating, complemental, figure-of-8 curves arranged in different planes, which approximate but never interlock. A locking movement of the extremities would render locomotion impossible. It follows that men and animals can, by the aid of their extremities, which move in free spiral curves, perform long journeys without difficulty. As is well known, the bodies of vertebrate animals are bilaterally symmetrical. This is especially true of man, who may be regarded as the paragon of living forms. In order to bring about this bilateral symmetry the body is composed of right and left-handed spiral segments, the one slightly overlapping and dominating the other. This view is favoured by the fact that antelopes and other animals which grow spiral horns invariably produce a right-handed spiral on one side of the head and a left-handed spiral on the other or opposite side of the head. The overlapping, stronger, and more active segment or half of the body practically settles the question of right- and left-handedness, the individual being right-handed when the right segment and left-handed when the left segment is in the ascendancy. The brain, as the controlling agent, is a leading factor in determining whether an individual is to be right or left-handed.

Without entering into the subject too minutely, it is safe to assert that the one side of the body is almost invariably stronger than the other, and that this greater strength, however produced, inclines the individual to use that side, and the extremities of that side, the most. This is well seen in the lead taken by one or other extremity in walking. If the eyes be blindfolded it is not possible to walk in a perfectly straight line. It is found, moreover, next to impossible to walk in a perfectly straight line even when the eyes are open and fixed on a given object. Unconsciously, the heavier, stronger, and more active half of the body asserts itself, and the individual

swerves in curves to the right or left in spite of himself. The curved spiral movements of the limbs and the trend to the right or left in particular instances explain why natural footpaths in fields and waste places are almost invariably tortuous and winding. The spiral arrangements to which reference has been made culminate in the movements of walking, swimming, and flying. These important movements, on which the lives of the higher animals largely depend, are, as I showed in 1867 and subsequently,[1] distinctly spiral in their nature. When a man walks he twists his body at the shoulders and hips diagonally, the right arm and left leg advancing together to form one step, the left arm and right leg advancing together to form a second step. The right arm and left leg in walking make opposite spiral curves, and these are crossed by similar curves made by the left arm and right leg, the result being a series of double figure-of-8 curves. The same thing happens when a bird swims by the aid of its feet. In this case the right leg with the right webbed foot fully expanded is during the effective stroke thrust in a backward direction and makes a right-handed curve ; the right foot, which during the non-effective stroke is closed and drawn towards the body, making a left-handed curve. The left leg and foot perform similar movements, and as the right and left legs and feet act alternately, double or figure-of-8 curves are generated. Similar remarks are to be made of the movements of quadrupeds. These, however, are slightly more complicated. Thus, in the walk of the horse the body is alternately supported on diagonals formed by the right fore and left hind legs and the converse ; on laterals formed by the right fore and right hind legs and the converse ; and on tripods formed by the two fore legs and one hind leg and the converse. In one stride the body is successively supported (1) by the two hind legs and the left fore leg ; (2) by the left fore and right hind legs ; (3) by the two fore and right hind legs ; (4) by the right fore and right hind legs ; (5) by the right fore and the two hind legs ; (6) by the right fore and left hind legs ; (7) by the two fore and left hind legs ; and (8) by the left fore and left hind legs.

The supports formed by the legs of the horse vary in the several paces, such as the trot, the gallop, the amble, &c. The outstanding feature in all the paces is the twisting movements of the body at the shoulders and hips, and the sinuous, double figure-of-8 curves made by the legs and feet on leaving and reaching the ground. These double-curved movements are well seen in the swimming of the fish, especially the long-bodied fishes. In swimming the body of the fish is thrown into alternating, complemental, cephalic, and caudal curves. Generally the sinuous double-curve movements can be traced also in the pectoral fins of fishes, these fins being the homologues of the anterior extremities of quadrupeds and bipeds. They invariably occur in the tail, which is lashed from side to side by a sculling movement. The tail of the fish is made to vibrate laterally, and while so engaged it twists upon its root or axis in such a manner as to produce double curve, figure-of-8 movements. The pectoral and caudal fins of fishes are of a generally triangular shape, and are beautifully graduated, tapering, elastic structures. They closely resemble wings both in structure and function. They are all propelling organs. If the pectoral fin of the thresher shark (*Carcharias vulpes*) be examined it will be found that it is triangular-shaped, thick, and semi-rigid at the root and along the anterior margin, and thin and elastic at the tip and along the posterior margin. This is the type of all wings, as an inspection of the wing of an insect, bird, or bat will show. Wings are slightly twisted upon themselves structurally, and are screws functionally. The main difference between the pectoral fins of the shark and the wings of flying creatures consists in the greatly increased size of the latter. In only one case —namely, that of the flying-fish—do the pectoral fins approach the wings in dimension. The flippers of the dolphin, whale, and sea-bear resemble the pectoral fins of the shark both in form and function. The fins and tails of fishes and the flippers of sea mammals simply propel. The wings of insects, birds, and bats propel, elevate, and sustain. Fins, wings, and flippers, however, act on a common principle, which finds its expression in the sinuous, double curve, figure-of-8 movements referred to in the walking of the quadruped and biped and in the swimming of the bird and fish. That wings act as explained can readily be verified by holding a bluebottle fly or bee against a dark background in a strong light when the wings are vibrating rapidly. The blur or impression produced on the eye of the spectator by the swiftly moving wing is twisted figure-of-8 fashion, a circumstance due to a change of plane in the wing and to the fact that the wing acts spirally in two directions as it hastens to and fro, the double curves forming one-half of the 8 being developed during the forward stroke and the double curves forming the other half of the 8 being developed during the back or return stroke. In free flight the figure-of-8 is opened out spirally, the wing in this case making a waved trajectory in space. In the insect the wing acts more horizontally than in the bird and bat. In the bird and bat the spiral figure-of-8 movements made by the wings can be readily detected by a practised eye and careful observation. When the wings of the bird and bat are made to vibrate in captive or slow flight the tips of the wings make more or less vertical figure-of-8 trajectories. In free, rapid flight the

[1] "On the Various Modes of Flight in Relation to Aëronautics" (*Proceedings of the Royal Institution of Great Britain*, 1867) ; "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom" (*Transactions of the Linnean Society*, vol. xxvi., 1867) ; "On the Physiology of Wings" (*Transactions of the Royal Society of Edinburgh*, vol. xxvi., 1870) ; "On Animal Locomotion" (Anglo-American Science Series, 1873), &c.

figures-of-8 made by the wings are opened out and spirally unravelled, and form waved trajectories—as in insects. To this there is no exception, as I have very fully convinced myself alike by observation and experiment. In birds and bats the wings are more or less folded and shortened during the up-strokes and expanded and lengthened during the down-strokes. The wings of birds and bats, as I first pointed out in 1867, strike downwards and *forwards* during the down-stroke and upwards and *forwards* during the up-stroke. This view, wholly opposed to prevailing beliefs, was much debated at the time, but has been strikingly and amply corroborated by instantaneous photographs of flying birds taken by Mr. E. Muybridge and others. In these photographs—those of the pigeon, *e.g.*—the tips of the wings at the *beginning* of the down-stroke are as far back as the extremity of the tail, whereas at the *end* of the down-stroke they are in advance of the beak of the bird the whole length of the body or more. The old idea was that the wings *pushed* the body of the flying creature forward ; in reality, the wings always fly in advance of the body and *pull* it forward. The result is the same, but the *modus operandi* is wholly different.

In all natural wings and in all artificial wings properly constructed the figure-of-8 and waved movements are invariably developed in captive and free flight. The great interest taken in artificial flight of late years invests the subject of the present article with a new zest, and this has been heightened by the recent publication (1903) of a small work by Mr. Theodore Andrea Cook, M.A., entitled "Spirals in Nature and Art : a Study of Spiral Formations based on the Manuscripts of Leonardo da Vinci, with special reference to the Architecture of the Open Staircase at Blois, in Touraine." Mr. Cook in the work in question has attributed, rightly or wrongly, to that celebrated artist, architect, and engineer a large number of the most important discoveries of modern times. I say rightly or wrongly, as Mr. Cook adduces no proof to show that Leonardo actually made the discoveries which he has assigned to him —proofs, it appears to me, being required in the case of a savant who died several centuries ago and whose writings are very little known. In the matter of flight the claims which Mr. Cook makes for Leonardo are wholly unwarranted —indeed, wholly opposed to facts. Thus at pp. 153 and 154 of his book he says : "The downward stroke of a bird's wing, which is supposed to be so new a revelation of the instantaneous camera, was noted independently by Leonardo. He observed, too, that as the tips of a bird's wings in flight go up and down as well as onwards they make a spiral in the air which is adapted to the strength of wind resistance it has to encounter, and he made use of this observation in his theory of flying-machines. His brain was able to infer what no human eye could really see, and when he noted that the spiral formation of a screw was suggested by the movement of a flying bird, it was not till 400 years afterwards that the truth of the inference could be visibly demonstrated." Mr. Cook, in support of the claim which he sets up for Leonardo, appropriates (*vide* Fig. 45 of his book) two of my original figures, which he assigns to Leonardo without acknowledgment. In this connection I have to state that Mr. Cook, in a recent issue of *Nature* (July 30, 1903), has frankly admitted that he inadvertently appropriated my figures. In his apology however, he avers that my figures are of very little importance to his argument. He gives with the one hand and takes with the other. The statement quoted above is altogether inaccurate, and is not justified, even indirectly, by any passage or drawing occurring in the manuscripts of Leonardo da Vinci, which I have carefully examined. As a matter of fact, Mr. Cook, in his great admiration of Leonardo, unwittingly reads into Leonardo's short treatises and notes on natural and artificial flight the discoveries on these subjects of the last thirty-six years. He gives to the sixteenth century what unquestionably belongs to the nineteenth century. Leonardo's chief work on flight, bearing the title "Codice sul Volo degli Uccelli e Varie Altre Materie," written in 1505, consists of a short manuscript of twenty-seven small quarto pages, with simple sketch illustrations interspersed in the text. In addition he makes occasional references to flight in his other manuscripts, which are also illustrated. In none of Leonardo's manuscripts, however, and in none of his figures is the slightest hint given of his having any knowledge of the spiral movements made by the wing in flight or of the spiral structure of the wing itself. Mr. Cook, as explained, also claims that Leonardo knew the direction of the stroke of the wing as revealed by recent researches and proved by modern instantaneous photography. As a matter of fact, Leonardo gives a wholly inaccurate account of the direction of the stroke of the wing. He states that the wing during the down-stroke strikes downwards and *backwards*, whereas in reality, and as demonstrated by me in 1867, it strikes downwards and *forwards*. In speaking of artificial flight Leonardo says, "The wings have to row downwards and backwards to support the machine on high, so that it moves forward." In speaking of natural flight he remarks, "If in its descent the bird rows backwards with its wings the bird will move rapidly ; this happens because the wings strike the air which successively runs behind the bird to fill the void whence it comes." There is nothing in Leonardo's writings to show that he knew either the anatomy or physiology of the wing in the modern sense. He certainly did not know that the wing is a screw structurally and functionally ; that in captive flight it makes a figure-of-8 track ; that in free flight the figure-of-8 is opened out to form first a spiral and then a waved trajectory, and that it strikes downwards and *forwards* during the down-stroke, the wings pulling and not *pushing* the bird as Leonardo and all those who followed him believed.

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